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The mission of the IJISPM - International Journal of Information Systems and Project Management - is the dissemination of new scientific knowledge on information systems management and project management, encouraging further progress in theory and practice.

The IJISPM publishes leading scholarly and practical research articles that aim to advance the information systems management and project management fields of knowledge, featuring state-of-the-art research, theories, approaches, methodologies, techniques, and applications.

The journal serves academics, practitioners, chief information officers, project managers, consultants, and senior executives of organizations, establishing an effective communication channel between them.

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- chief information officer role
- information technology leadership role
- chief information officer skills
- information systems management tools
- management of complex projects
- audits
- innovation
- ethics
- benefits management
- project environment
- project management life-cycle
- project initiation
- project planning
- project execution
- project control and monitoring
- project closing
- success criteria and success factors
- project manager role
- project manager skills
- portfolio management
- program management
- managing organization - structure
- tools and techniques
- project evaluation
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- project management knowledge areas
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Editorial

The mission of the *IJISPM - International Journal of Information Systems and Project Management* is to disseminate new scientific knowledge on information systems management and project management, encouraging further progress in theory and practice.

We are pleased to bring you the first number of the 12th volume of IJISPM. In this issue, readers will find important contributions on information systems management, software quality, adoption of information technology, and project management education.

The first article, "Traction with fraction: Strategic IS management in SMEs through Fractional CIOs", is authored by Simon Kratzer, Markus Westner and Susanne Strahringer. According to the authors, small and medium-sized enterprises (SMEs) increasingly need to manage information technology (IT) effectively to remain competitive. However, compared to larger organizations, SMEs often face challenges in terms of resources and employer attractiveness and regularly do not need to employ a Chief Information Officer (CIO) on a full-time basis. To address this issue, a growing number of global experts have begun to provide CIO services part-time for multiple clients simultaneously. This approach allows SMEs to tap into the expertise of experienced IT leaders at a fraction of the cost and without committing to long-term arrangements. While these professionals, known as "Fractional CIOs", have proven their value in the field, there has been a lack of academic research on this emerging trend. The authors carried out a comprehensive research project between 2020 and 2023 involving 62 Fractional CIOs from 10 countries. The research produced a definition, different types of engagements, and success factors for Fractional CIOs and their engagements.

The title of the second article is "Tools for monitoring software quality in information systems development and maintenance: five key challenges and a design proposal", which is authored by Rolf-Helge Pfeiffer and Jon Aaen. As software grows in size and complexity, organizations increasingly apply tools to automatically assess the software quality of information systems during development and maintenance. Software quality assessment tools (SWQAT) promise fast and actionable insights into the technical state of software through various quality characteristics, such as maintainability, reliability, or security. These tools have been used to support a wide variety of IT project management decisions related to system development, contract negotiations, project terminations, and even settling legal disputes between suppliers and clients. However, despite their rising importance, questions regarding how they function and how reliable they are to support decision-making have escaped scholarly attention. This paper evaluates widely used SWQATs and analyzes how they rate the quality of software systems of varying sizes, functionalities, and programming languages. Results reveal five key challenges for using SWQATs in IT projects. To address these challenges, the authors propose a design for tailorable SWQATs that allows for more conscious and prudent software quality assessments that better reflect the socio-technical aspect of software systems and the context-specific nature of software quality.

The third article, authored by Daniel de Vargas and Lisandra Manzoni Fontoura, is entitled "Problems and solutions in adopting information and communication technology in micro and small enterprises". Micro and small enterprises (MSEs) are predominant worldwide and responsible for the greater employability of citizens, income generation, and production. However, they face resource constraints and rely on information and communication technology to remain competitive, which often causes more problems during or after the adoption process. Knowing the problems that affect micro and small enterprises and the solutions adopted may help other companies face the same problems. In this work, based on a systematic literature review (SLR), the authors identified and analyzed the problems that occurred during or after implementing information and communication technologies in micro and small enterprises and what actions were

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taken to solve them. The authors sought to understand the behavior of problems and solutions in the last 21 years and the factors that influenced them. The authors identified 129 problems, divided into 12 categories, and 48 solutions.

"Metaverse adoption for the teaching and learning of project management: an exploratory study of student use" is the fourth article and is authored by Alanah Mitchell. The rapid adoption of collaboration technologies throughout the COVID-19 pandemic and the advancement, growth, and proliferation of metaverse technology capabilities have created a heightened awareness and comfort with using advanced collaboration technologies for online and distance education. This paper presents an exploratory study of how metaverse technologies can be adopted for teaching and learning project management concepts and skills specifically, as metaverses have been identified as legitimate tools for supporting virtual projects. As a part of this work, a task was designed and adopted in an undergraduate project management course. Study results related to the teaching and learning of project management and student perceptions of metaverse technology adoption show that students could work together in a metaverse environment and collaborate with one another to achieve group consensus on a task. Ultimately, the findings from this case can guide future adoptions of metaverse technologies both in and out of the classroom.

We would like to take this opportunity to express our gratitude to the distinguished members of the Editorial Board for their commitment and for sharing their knowledge and experience in supporting the IJISPM.

Finally, we would like to express our gratitude to all the authors who submitted their work for their insightful visions and valuable contributions.

We hope that you, the readers, find the International Journal of Information Systems and Project Management an interesting and valuable source of information for your continued work.

The Editor-in-Chief,

João Varajão

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João Varajão is a professor of information systems (IS) and project management (PM) at the University of Minho. He is also a researcher at the ALGORITMI/LASI research center. Born and raised in Portugal, he attended the University of Minho, earning his Graduate (1995), Masters (1997), and Doctorate (2003) degrees in Technologies and Information Systems. In 2012, he received his Habilitation from the University of Trás-os-Montes e Alto Douro. His main research interests are IS PM, IS Development, and IS Management (addressing PM success and the success of projects). Before joining academia, he worked as an Information Technology (IT)/IS consultant, project manager, IS analyst, and software developer, for private companies and public institutions. He has supervised over 140 MSc and PhD theses. He has published more than 300 works, including refereed publications in journals, authored books, edited books, book chapters, and communications at international conferences. He serves as editor-in-chief, associate editor, and editorial board member for international journals. He has served on numerous committees for international conferences. ORCID: 0000-0002-4303-3908

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Traction with fraction: Strategic IS management in SMEs through Fractional CIOs

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Traction with fraction: Strategic IS management in SMEs through Fractional CIOs

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Abstract:
Small and medium-sized enterprises (SMEs) increasingly need to manage information technology (IT) effectively in order to remain competitive. However, compared to larger organizations, SMEs often face challenges in terms of resources and employer attractiveness, and regularly do not have the need to employ a Chief Information Officer (CIO) on a full-time basis. To address this issue, a growing number of global experts have begun to provide CIO services on a part-time basis for multiple clients simultaneously. This approach allows SMEs to tap into the expertise of experienced IT leaders at a fraction of the cost and without committing to long-term arrangements. While these professionals, known as “Fractional CIOs”, have proven their value in the field, there has been a lack of academic research on this emerging trend. Therefore, we carried out a comprehensive research project between 2020 and 2023, involving 62 Fractional CIOs from 10 countries. The research produced a definition, different types of engagements, and success factors for Fractional CIOs and their engagements. This paper summarizes these findings for a wider audience of academics and practitioners.

Keywords:
fractional CIO; Chief Information Officer; SMEs; small businesses.

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1. Introduction

The role of the Chief Information Officer (CIO) has been the subject of information systems research for over four decades [1–3]. As the importance of information technology (IT) within companies continues to grow, the establishment of strategic IT management has become increasingly important over time [4]. Effective IT management is essential for both large enterprises and small to medium-sized enterprises (SMEs) to gain a competitive advantage [5, 6]. While larger companies typically appoint a full-time CIO for this purpose [4], SMEs often face challenges due to limited resources and employer attractiveness when considering the employment of a full-time CIO [7, 8]. As an alternative, SMEs often turn to external help or assign IT responsibilities to a manager with a different primary focus [9]. However, these involuntarily assigned IT managers are often preoccupied with other responsibilities, which can lead to reduced productivity and expose the company to security risks [5, 10].

To fill this gap, there are many experts around the world who have started to offer CIO services to SMEs on a part-time basis. These so-called “Fractional CIOs” (also known as “Virtual CIOs”, “CIOs for hire”, or “part-time CIOs”) are often highly experienced IT professionals who work as CIOs for several companies at the same time [11–13]. This gives SMEs access to IT experience and expertise at a fraction of the cost and without making a long-term commitment. While the role of the Fractional CIO is becoming increasingly popular in practice [14, 15], there has been little relevant research on the subject to date. Therefore, we launched a major research project in November 2020 with the participation of Fractional CIOs from 10 different countries to investigate the role of the Fractional CIO. We derived a definition of the role and different types of engagements [16], identified and evaluated factors for the success of Fractional CIO engagements [17, 18], and analyzed the Fractional CIO’s role in mainland Europe, namely the German market [17]. Partially similar to an article we published recently in German [19], this article summarizes the findings of the research project with the intention of making them accessible to a wider audience of academics and practitioners. We aim to stimulate further research in this area and invite industry to consider this role as a useful means of driving digitalization in SMEs.

The article is structured as follows: First, we provide an overview of the studies and methods used. Then, we present the findings from the previous studies on the Fractional CIO. We conclude the article by discussing limitations and areas for future research.

2. Background

In this article, we summarize our three preceding studies regarding the role of the Fractional CIO (see Table 1).

Table 1. Overview of the three preceding Fractional CIO studies [16–19]
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	Fractional CIO study #1	**Fractional CIO study #2**	**Fractional CIO study #3**
Reference	Kratzer et al. [16]	Kratzer [17], Kratzer et al. [18]	Kratzer et al. [19]
Title	The Fractional CIO in SMEs: Conceptualization and research agenda	Factors for Fractional CIO engagement success	Beyond full-time: Fractional CIOs in SMEs
Number of Fractional CIOs participating in the study	40	48	3
Research focus	Conceptualization of the Fractional CIO role and identification of engagement types	Empirical evaluation of the relative importance of factors influencing Fractional CIO engagement success and identification of different viewpoints on engagement success	Analysis of the Fractional CIO role in the German market
Section	3.1, 3.2	3.3	3.4

In the first study on Fractional CIOs [16], we conducted 40 semi-structured, exploratory interviews with Fractional CIOs from a total of 10 different countries between November 2020 and April 2021. For this purpose, we first developed a set of key questions taking into account existing research and practice reports [e.g., 1, 12, 13, 20, 21]. We then contacted a total of around 500 potential interview candidates via personal contacts and LinkedIn. If they expressed interest, we conducted semi-structured interviews with these Fractional CIOs according to the guidelines proposed by Myers and Newman [22]. We conducted a total of 39 interviews in English and one interview in German via video conference. The average duration of the interviews was 40 minutes. All interviews were recorded, carefully transcribed, coded, and analyzed. Finally, we derived concepts based on the identified categories and codes and interpreted the results in a meaningful way.

The second study on the Fractional CIO was conducted in two phases. First, between May and September 2021, we developed a framework of success factors for Fractional CIO engagements [17]. We used the analyzed interview data from the first Fractional CIO study [16] to quantitatively and qualitatively assess specific topics of interest. Within these topics, all factors that were mentioned by at least 20% of respondents were considered and all factors were grouped thematically. The resulting framework consists of four components: the *Fractional CIO*, the *client*, their *relationship*, and the *engagement setup* (see Figure 1). Each component in turn comprises several factors that influence the success of the engagement.

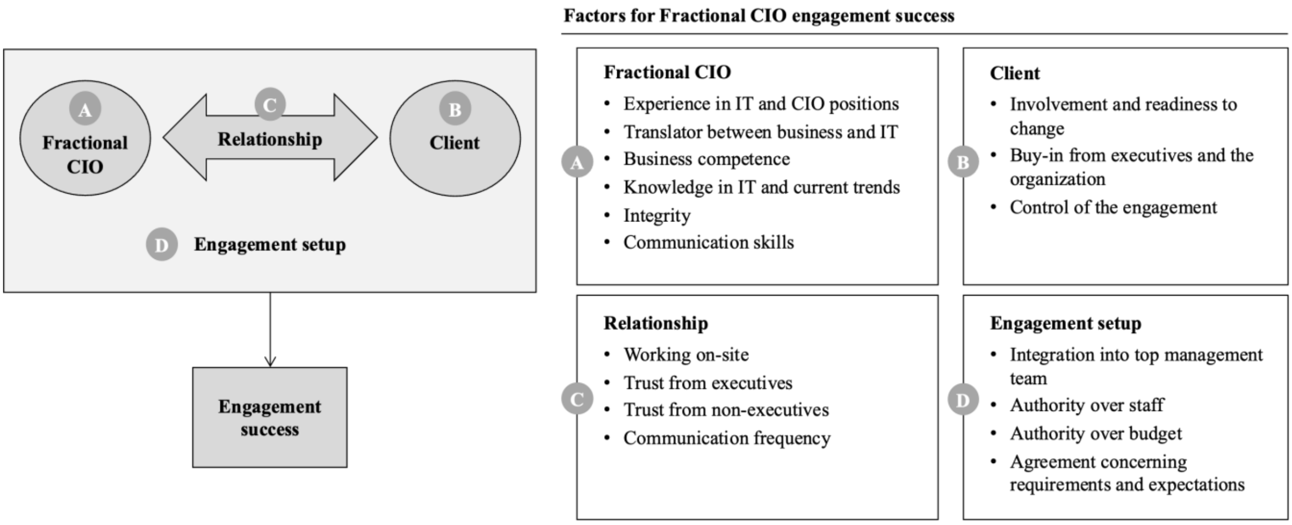

Figure 1. Research framework for Fractional CIO engagement success [17]
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In a second step, we conducted a Q-method-based study [23] with 48 Fractional CIOs between September 2021 and July 2022. The aim of this study was to sort the factors for the success of Fractional CIO engagements according to their importance and identify different viewpoints on success among the Fractional CIOs [18]. The Q-method aims to identify respondents' subjective viewpoints, i.e., their individual opinion or evaluation of a particular issue [24–26]. To perform the Q-method, a Q-sample with statements must first be extracted from a so-called "concourse". A concourse is a collection of all possible statements on a specific topic [23]. We created the concourse for the success factors of Fractional CIO engagements based on the research framework from Kratzer [17] (see Figure 1). Using existing literature from the fields of CIO [e.g., 27] and consulting [e.g., 28] as well as empirical data from the interviews by Kratzer et al. [16] and expert interviews, we extracted a representative Q-sample with 25 statements from the concourse.

The 48 Fractional CIOs then performed Q-sorting by sorting the 25 statements into a pyramid-shaped, forced quasi-normal distribution with nine levels. The levels of the pyramid range from -4 (least important) to 4 (most important), with room for five statements in the middle column (0, neutral). We excluded a total of 12 results as the CIOs did not match our definition of a Fractional CIO. Based on the 36 usable responses, we first identified the general factors for Fractional CIO engagement success. We then performed a principal component analysis with Varimax rotation. The resulting three factor solutions represent groups of Fractional CIOs who have a similar opinion regarding the importance of the factors. For the interpretation of the Fractional CIO groups, we analyzed the differentiating statements between the factor solutions [29]. Differentiating statements are those statements that show the highest variance across all factor solutions.

For the third study, we conducted three additional semi-structured interviews between June 2022 and May 2023 with experienced Fractional CIOs/CTOs from Germany to obtain a mainland Europe perspective [22]. For this purpose, we translated the questionnaire from Kratzer et al. [16] into German and expanded it to include specific questions on the topic of Fractional CIOs in Germany, such as reasons for the low prevalence and possible challenges specific to Germany. We conducted and recorded the interviews in German via video conference, with each interview lasting approximately 50 minutes. We then transcribed, coded, analyzed, and interpreted the interviews in a similar way to the first Fractional CIO study [16].

3. The Fractional CIO

3.1 Conceptualization of the Fractional CIO role

The Fractional CIO role offers a novel approach to tackling many of the IT management challenges that SMEs face today. Fractional CIOs provide access to highly experienced IT leaders at a fraction of the cost. The role also combines the benefits of a full-time employee (i.e., integration into internal structures and interest in the success of the business) with those of a consultant (i.e., bringing an external perspective and flexibility). If an SME wants to differentiate itself from its competitors, it is probably better to employ a Fractional CIO for 1 to 3 days per week than a full-time IT executive who may lack experience and strategic vision.

In the first study, we derived a definition of the Fractional CIO role from 40 interviews and by analyzing existing literature. The 40 interviewees gave numerous role designations: e.g. *Virtual CIO*, *Part-Time CIO*, *CIO-on-Demand*, or *vCIO*. While some respondents used multiple role titles, the majority described themselves as Fractional or Virtual CIO. However, most do not see a difference between the two terms. Smith and Sinclair [30] define a virtual executive as someone who leads employees, works at least some of the time in a different geographical location from their team, and communicates with their employees by means other than regular face-to-face contact, such as email or telephone. According to this definition, a “virtual” CIO could also be a full-time employee. To avoid ambiguity, to emphasize the part-time nature of the role, and to clearly describe the phenomenon, we chose the term “Fractional CIO”.

There are also clear differences in the structure of the Fractional CIO role. The interviewees who have been in this role for more than 10 years did not know any other people offering such a service when they started this activity. This fact underlines the scattered and heterogeneous development of the role and the service model. Nevertheless, there was clear agreement on many points. By combining the key similarities, we define a Fractional CIO as “a highly experienced and competent individual that acts in the capacity of a CIO, but only part-time, depending on the clients’ needs. The Fractional CIO serves multiple clients at the same time and often has the authority and responsibility of a full-time CIO and (in-) directly manages each of his/her clients’ IT staff and suppliers” [16, 588, 591].

There is a difference between a Fractional CIO and a full-time CIO or consultant. Figure 2 illustrates the positioning of a Fractional CIO between a full-time CIO and a consultant along various dimensions. While the role of a full-time CIO has different characteristics and incentives than that of a consultant, both roles have certain advantages for organizations. On the one hand, a full-time CIO tends to stay with the company for the long term, is well integrated into the organization, and has limited incentive to generate “follow-up” work. On the other hand, a consultant is flexibly tied to the organization and brings an outside-in perspective as well as a high level of experience from different areas. A

Fractional CIO, who is positioned between the two roles, combines the integrity and long-term perspective of a full-time CIO with the flexibility, experience, and outside-in perspective of a consultant.

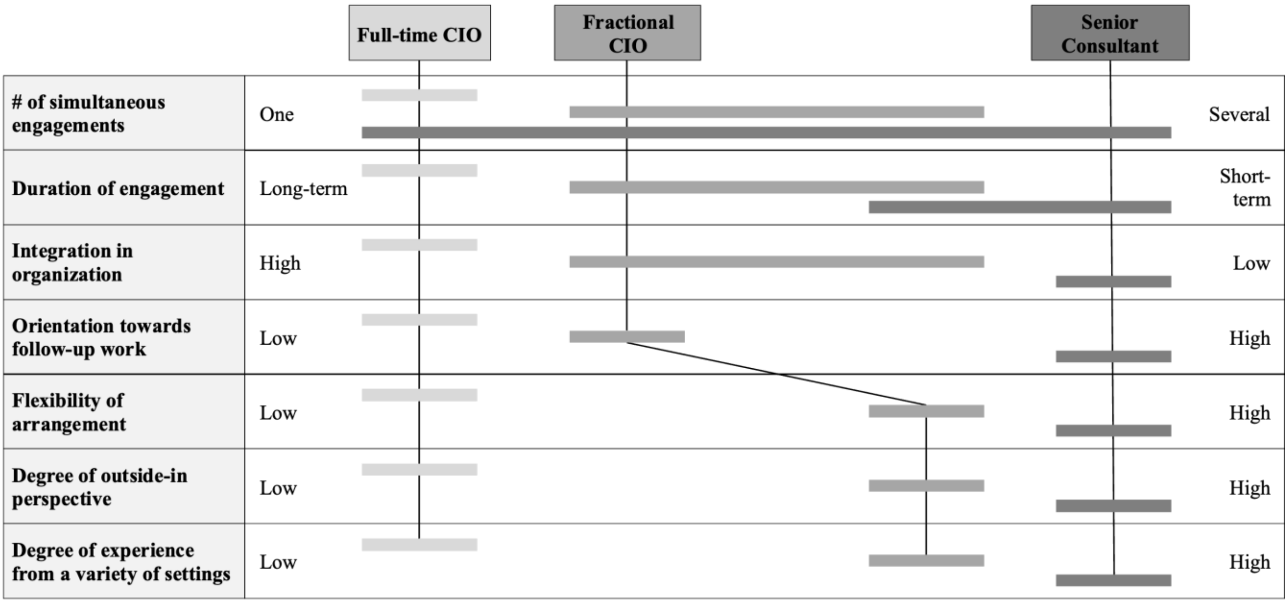

Figure 2. Differences of a Fractional CIO compared to a full-time CIO or consultant [16]
(translated figure from [19] licensed under CC BY 4.0 DEED Attribution 4.0 International - https://creativecommons.org/licenses/by/4.0/)

Often the responsibility for IT in an SME lies with an employee with a different functional background, e.g., the CFO. For an SME with an existing IT department including an IT manager, a Fractional CIO is superfluous as there is already a manager in place.

3.2 Fractional CIO engagement types

Through the 40 interviews in our first study, we identified a variety of reasons why SMEs hire a Fractional CIO. Fractional CIOs were found to tailor their value proposition specifically to the needs of their clients. In synthesizing these value propositions, we identified four different engagement types that Fractional CIOs pursue (see Figure 3). The different engagement types can be categorized into a continuum ranging from strategic and demand-driven, i.e., enabling new business models, to operational and supply-driven, i.e., “keeping the lights on”. While *strategic IT management* focuses primarily on supporting the company, *hands-on support* is an operational engagement. The *restructuring* and *rapid scaling* types are in between. The engagement types offer added value in different client situations, and each type has its own value proposition. Which engagement type is most suitable depends on the specific needs of the company. Each of the engagement types is presented in more detail below.

In the *strategic IT management* engagement type, the client generally requires strategic IT management, as there is a lack of alignment between IT and the business. In addition, the client usually has an existing IT department with several employees. The value proposition of the Fractional CIO in this case is to work on the strategic IT alignment and to establish good relationships and collaboration between IT and the business. To do this, the Fractional CIO needs strong communication skills and must focus on strategic issues.

In the *restructuring* engagement type, too, the client usually has an existing IT department. However, the department typically has serious problems, e.g., is regularly over budget, is severely underinvested, or has outdated IT. The Fractional CIO helps to solve urgent problems, restructure the IT organization, and build IT capabilities. Towards the end of an engagement, the Fractional CIO transitions the company's IT to a stable state and carries out a handover, e.g., by hiring a new CIO. For such engagements, the Fractional CIO requires restructuring experience and expertise in the areas of IT auditing and reorganization.

The *rapid scaling* engagement type describes the collaboration of a Fractional CIO with a start-up company that does not yet have an IT department but expects rapid growth. The Fractional CIO's tasks include setting up a suitable IT structure and architecture, building an IT department and providing IT leadership skills, and finally hiring a full-time CIO to take over the company's IT. The Fractional CIO should have experience in building and scaling an entire IT department.

The final engagement type, *hands-on support*, is aimed at companies without their own IT department that are dependent on external IT suppliers. In such scenarios, the Fractional CIO often remains long-term and acts as a buffer between the organizations and their IT suppliers. In addition, the Fractional CIO helps to keep IT running smoothly from an operational perspective.

Figure 3 illustrates the four engagement types, outlines typical client situations, and depicts the Fractional CIOs' specific value propositions in these contexts.

Types	Typical client situation	Value proposition
Strategic IT management	• Missing connection between IT and the business • Need for strategic IT management • Usually several employees in IT	• Establishing good relationship and collaboration between IT and the business • Working on strategic IT direction
Restructuring	• Severe problems in IT (regularly over budget, heavily underinvested) • Usually several employees in IT	• Solving urgent problems and restructuring the IT organization • Building up IT capabilities • Transitioning into steady-state and handover
Rapid scaling	• Start-up with no IT yet, expecting rapid growth • Usually no IT department in the beginning	• Setting up proper structure and architecture • Building an IT department and providing IT Leadership • Hiring a full-time CIO to take over
Hands-on support	• No in-house IT (everything outsourced) • Often dependent on MSPs/ vendors	• Staying long-term • Acting as "protection" between client and vendors • Helping to run IT smoothly ("Keeping the lights on")

Figure 3. Typical client situations and Factional CIO value propositions according to the 4 identified engagement types [16]
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3.3 Factors for Fractional CIO engagement success

In the second study, we initially developed a framework for Fractional CIO engagement success (see Figure 1). Building on this, we conducted the Q-method with 36 Fractional CIOs. On the one hand, we derived overarching, general factors for the success of an engagement, and on the other hand, we derived specific success factors for each Fractional CIO group within the three factor solutions. We first present the general factors for success, followed by the individual Fractional CIO groups and their respective subjective views.

The key to a successful engagement is the relationship with the client's leadership team, which manifests itself through trust. The second most important general factor for the success of an engagement is integrity. While companies that do not have the appropriate technical expertise run the risk of being taken advantage of by their IT suppliers, the Fractional CIO is often seen as an objective and loyal contact. The third and fourth general factor for Fractional CIO engagement success is support from the client's leadership team and effective communication between the Fractional CIO and the leadership team.

Through a careful evaluation of the descriptive statistics and interpretation of the individual factor solutions, i.e., the groups of Fractional CIOs who share similar views, we labeled them as follows: *strategic IT advisors*, *full-ownership CIOs*, and *change agents* (see Figure 4). Each of the three groups of Fractional CIOs has different characteristics and opinions on the success factors of engagements. In the following, we first discuss the different characteristics of the Fractional CIO groups. Then we present the views of each group on the factors for Fractional CIO engagement success.

	Strategic IT Advisor *often serves multiple clients simultaneously with varying IT department sizes*	**Full-Ownership CIO** *usually has clients with smaller IT departments or even no IT department at all*	**Change Agent** *typically serves larger clients and, hence, needs to limit the number of engagements*
Avg. # of simultaneous client engagements	5	4	3
Avg. size of IT department (in FTE)	7	4	18
Avg. IT Budget (in mn USD)	≈ 4.5	≈ 1	≈ 3.5
Most important factors for success	• Strategic thinking • Integrity • Suitable business competence • Ability to switch context quickly and effectively	• Alignment on requirements and expectations • Effective communication with and support from the client's non-executive staff • At least partial authority over the client's staff	• Integrity • Fit with organizational culture • Willingness to change of the client's staff • At most three simultaneous engagements

Figure 4. Description of the three Fractional CIO groups and their most important factors for success [18]

While the *change agents* have an average of three clients at the same time, the *full-ownership CIOs* have four. This corresponds to around 1.3 to 1.7 days per client per week. *Strategic IT advisors*, on the other hand, have an average of five simultaneous engagements, i.e. around one day per client. While *strategic IT advisors* and *change agents* tend to support larger clients with an average of 260 and 349 FTEs respectively, *full-ownership CIOs* focus on smaller clients with an average of 66 FTEs. This is also reflected in the size of the IT department: the *full-ownership CIOs* work with IT departments with an average of 4 FTEs, the *strategic IT advisors* with around twice that and the *change agents* with four to five times that.

However, the three Fractional CIO groups not only have different characteristics in terms of the number of concurrent clients and client size, but also have significantly different views on which factors particularly contribute to the success of an engagement. We present the three groups and their views in detail below.

The first group, *strategic IT advisors*, support their clients at a strategic level in terms of how they can develop the business through IT. Fractional CIOs must act with integrity, think strategically, and have appropriate business skills to build the necessary trust. They also need to be able to change context quickly and effectively, as they often manage multiple clients with different sized IT departments at the same time. The ability to think strategically is the key differentiator for *strategic IT advisors*. In addition, there is a strong focus on business expertise and how IT supports the business.

Knowledge and broad experience in IT are also essential. In order to create the necessary trust, the Fractional CIO must act with integrity. Since the position offers various opportunities to emphasize one's own advantages – for example, by receiving a commission or similar from IT service providers when recommending them – integrity is one of the highest-rated factors. On average, the Fractional CIOs in this group have five clients at the same time, which means about one day per client per week. This requires effective time management.

Another factor is therefore the ability to change context quickly. Sometimes the *strategic IT advisors* are rather detached from the employees. In some cases, the lack of responsibility for the employees is also due to the different sizes of the IT departments. Although *strategic IT advisors* are the closest to traditional IT consultants, there are clear differences. On the one hand, Fractional CIOs often have line responsibility. Secondly, there is no real offer of strategic IT consulting, especially for small SMEs, while CIOs in large companies often have a kind of permanent consultant that they can call on by the hour or day. This gap is filled by *strategic IT advisors*.

The second group of Fractional CIOs, *full-ownership CIOs*, take full responsibility for the CIO position and therefore need a clear alignment on requirements and expectations regarding the engagement. They often need at least partial authority over their clients' employees. As a rule, *full-ownership CIOs* have clients with smaller IT departments with an average of four FTEs and sometimes even clients who have no IT department at all. Due to the more hands-on approach, effective communication with and support from the non-executive staff is required. Full ownership means that Fractional CIOs must not only support from a strategic IT perspective, but also ensure proper IT operations. This is especially true if the Fractional CIO is a one-person IT department and has to negotiate with IT suppliers, for example. As they deal with an average of four clients at a time, they need to ensure that they devote sufficient time to each client.

Another important factor for the success of a *full-ownership CIO* is the support of the company management. The relationship with the management team must also be cultivated. The fact that it is important for the success of this group of Fractional CIOs to have relevant experience in IT and CIO positions and at least partial authority over their clients' employees underlines the full ownership mentality. Some Fractional CIOs even have full management responsibility for the client's IT staff, including responsibility for hiring and firing.

The third group of Fractional CIOs, *change agents*, are part of the leadership team, act with integrity, and adhere to the highest professional standards. To facilitate change, it is important that these Fractional CIOs fit the organizational culture of their clients and build trusting relationships. Personal fit is also important.

Compared to the other groups of Fractional CIOs, *change agents* tend to have larger clients and therefore need to limit the number of engagements and spend at least a certain amount of time per week with each client. Fractional CIOs in this group have an average of 18 FTEs in the IT department and manage an average of three clients at a time.

Compared to *full-ownership CIOs*, *change agents* work at a much higher and strategic level and therefore do not focus as much on operational activities. Another critical factor in the success of the engagement is integrity. To facilitate change, these Fractional CIOs need to fit in with their clients' corporate culture. In addition, support from the client is required and employees must be open to change.

It is also more important for *change agents* to have no more than three concurrent assignments compared to the other groups of Fractional CIOs. Having more employees working in the IT department requires more commitment and time for each client.

The identified groups of Fractional CIOs with similar perceptions of success factors can be related to the engagement types described previously. *Strategic IT advisors* are most likely to operate in the *strategic IT management* engagement type. Fractional CIOs who belong to the *full-ownership CIOs* group are most likely to engage in the *hands-on support* engagement type, and slightly less likely to engage in the *strategic IT management* and *rapid scaling* engagement types. Finally, *change agents* will often see their engagement in *restructuring* settings with *strategic IT management* and *rapid scaling* being also likely engagement options. Figure 5 illustrates the mapping of the engagement types to the Fractional CIO groups and explains the rationale behind each mapping.

Engagement types \ Groups	Strategic IT Advisor	Full-ownership CIO	Change Agent
Strategic IT management	**Most common**	**Likely** Exemplary case: Small organization that needs help with IT strategy, but also IT operations	**Likely** Exemplary case: Organization that requires strategic IT direction besides change
Restructuring	**Unlikely** Full ownership required for *restructuring*, which is often not the case for the *Strategic IT Advisor*	**Unlikely** *Full-ownership CIOs* mostly serve smaller organizations, which rarely require extensive *restructuring*	**Most common**
Rapid scaling	**Unlikely** Full ownership required for *rapid scaling*, which is often not the case for the *Strategic IT Advisor*	**Likely** Exemplary case: A start-up that hires a Fractional CIO for scaling up fast	**Likely** Exemplary case: An established IT department that hinders the company's growth
Hands-on support	**Unlikely** Mostly concerned with IT strategy instead of IT operations	**Most common**	**Unlikely** *Change Agents* typically work on a more strategic level without too much involvement into IT operations

Figure 5. Mapping of Fractional CIO engagement types with Fractional CIO groups

3.4 The Fractional CIO in mainland Europe, namely in Germany

In the first two Fractional CIO studies, it was notable that there are hardly any Fractional CIOs to be found in Germany or other European countries outside Great Britain. Even the few German Fractional CIOs that were interviewed rarely knew other Fractional CIOs in Germany. Various opinions exist regarding the reasons for the limited presence of the role in Germany. One hypothesis is that European companies in general and German SMEs in particular might be too conservative. Others think it could be a lack of awareness of the problem and the Fractional CIO role. While there are different opinions about the limited prevalence, all interviewed Fractional CIOs agree that SMEs could greatly benefit from Fractional CIOs.

To establish the Fractional CIO role in European SMEs, it is crucial to enhance awareness of the role and understanding of its added value. Additionally, a receptiveness to new working models and problem awareness among company leaders is necessary. For SMEs, there should be an emphasis on strengthening awareness that the alternative to full-time employment does not automatically imply external consultancy. Figure 2 illustrates the two extremes with the Fractional CIO positioned in between, combining the best of both worlds for SMEs. Acting as an integrated part of the organization, often assuming line responsibilities, the Fractional CIO offers the flexibility of a consultant with a longer-term focus.

We outline concrete recommendations for the collaboration between Fractional CIOs and SMEs. For companies with small or no IT departments, *full-ownership CIOs* can provide operational and strategic support by taking responsibility for managing personnel and suppliers on behalf of their clients. A successful collaboration requires careful alignment of requirements and expectations, along with a high level of trust and clear decision-making authority for the Fractional CIO. *Strategic IT advisors* are the right choice for companies with existing IT departments that want to focus on strategic IT alignment and business support. Success in this context depends on the ability to combine business knowledge and technical understanding. Companies with established IT departments experiencing severe IT issues or requiring comprehensive transformation would benefit from collaborating with *change agents*. While capable of transforming the IT department, they are not typically responsible for operational IT functions [18].

Especially for SMEs in Germany, *full-ownership CIOs* seem to pose the most challenging option, as extensive directive powers and significant trust are often required. In contrast, *strategic IT advisors*, could be considered insufficient for the company's success. Nevertheless, or precisely because of this, *strategic IT advisors*, particularly with their proximity to IT consultants, form a potential starting point for collaboration with a Fractional CIO.

4. Conclusion

Our paper explored the evolving role of the Fractional CIO in SMEs, highlighting its strategic importance in information systems management for these organizations. We presented a comprehensive examination of the role's definition, responsibilities, engagement types, and success factors. The research was based on extensive interviews and surveys, providing a fundamental understanding of the importance of the Fractional CIO's significance in SMEs.

Our research was limited by its focus on a new role with a limited pool of participants, resulting in a non-representative sample. Reliance on the perspectives of individuals currently in the role may have introduced bias. While our exploratory approach was broad, further quantitative and case studies are needed for a more in-depth understanding.

Future research should examine regional and demographic variations in the Fractional CIO role and seek a balanced and neutral perspective by including the perspectives of organizations. Research on the opportunities and risks associated with the part-time nature, authority, and liability of the Fractional CIO is critical. Comparative studies with full-time CIOs would enhance understanding of the effectiveness and evolving nature of this role, paving the way for a comprehensive understanding in the field of information systems.

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Tools for monitoring software quality in information systems development and maintenance: five key challenges and a design proposal

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Abstract:
As software grows in size and complexity, organizations increasingly apply tools to automatically assess software quality of information systems during development and maintenance. Software quality assessment tools (SWQAT) promise fast and actionable insights into the technical state of software through various quality characteristics, such as maintainability, reliability, or security. These tools have been used to support a wide variety of Information Technology (IT) project management decisions related to system development, contract negotiations, project terminations, and even settling legal disputes between suppliers and clients. However, despite their rising importance, questions regarding how they function and how reliable they are to support decision-making have so far escaped scholarly attention. This paper conducts an evaluation of widely used SWQATs and analyzes how they rate the quality of software systems of varying sizes, functionalities, and programming languages. Our results reveal five key challenges for using SWQATs in IT projects. To address these challenges, we propose a design for tailorable SWQATs that allows for more conscious and prudent software quality assessments that better reflect the socio-technical aspect of software systems and the context-specific nature of software quality.

Keywords:
software quality assessment tools; information systems management tools; software quality; project control and monitoring.

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1. Introduction

World-class companies use software quality assessment tools (SWQAT) for information systems development and maintenance:

> *"We're using CAST [a software quality assessment tool] to measure the quality both as we're rolling things out in terms of our new code as well as looking at the legacy code that has come from the different partners to develop our core solutions over the last five or six years. This enables us to focus our mediation efforts on determining where we need to go back and deal with our quality issues. For us, an IT outage or a defect for something that's going into production can mean the trucks can't roll from the distribution center (...) and just a single day outage means multiple millions of dollars of lost revenue."*
> - Software Quality Assurance and Test Director, Coca-Cola Bottling and Investment Group [1]

Ensuring software quality is central to developing and maintaining Information Systems (IS) [2]. However, as the number and complexity of systems increase, it becomes progressively more demanding to continuously assess and monitor software quality through manual inspections. Consequently, organizations increasingly rely on tools to automatically rate the technical state of their software systems according to various quality characteristics such as maintainability, reliability, or security [3,4,5]. Contemporary software quality assessment tools (SWQAT) perform static analysis of a software system's source code to detect bugs, track technical debt, and ensure that coding and compliance standards are met [5]. Thereby, SWQATs can help developers detect potential weaknesses in the code that might lead to vulnerabilities or failure [6] while also providing managers with an overall understanding of a system's technical state [7].

SWQATs are used for a wide variety of purposes, including developing large-scale industrial software systems [8], as a basis for consultancy reports [3], contract negotiations [9,10], project terminations [11,12], and even settling legal disputes between suppliers and clients [13]. However, despite their growing importance for developing and maintaining information systems, IS research has paid little attention to the reliability of SWQATs, how they function, what they measure, and how suitable they are to support decision-making [6]. In this paper, we investigate these problems guided by the following research questions:

1. *What are the key challenges of using software quality assessment tools (SWQATs) to support decision-making in information systems development and maintenance?*
2. *How can SWQATs be designed to address these challenges?*

To address these research questions, we evaluate six prominent and widely used SWQATs. First, we map the fundamental features of each tool to analyze how they assess software quality and which metrics they use. Next, we analyze to which degree SWQAT ratings are consistent and comparable by testing the tools on a variety of software systems of different sizes, functionalities, and programming languages. Our results highlight five key challenges that cast doubt on the reliability of using contemporary SWQATs for information system development and maintenance. To overcome these challenges, we propose a design for tailorable SWQATs that allows for more conscious and prudent software quality assessments that better reflect the socio-technical aspect of software systems and the context-specific nature of software quality.

In the remainder of the paper, we first present extant literature on SWQATs and provide empirical examples of how SWQATs are used in information system development and maintenance. Next, we describe our research design and method before presenting our findings and design proposal. We conclude by discussing implications for research and practice. Our work expands current research by adding to the scarce literature on SWQATs in Information Technology (IT) project management.

2. Background: Software quality assessment tools in IS development and maintenance

Software quality has been a long-time concern in IT management, and organizations invest considerable resources in ensuring software quality during software development, maintenance, and evolution [5, 14, 15]. Poor software quality can have devastating consequences for multiple stakeholders, including user dissatisfaction, economic losses, and long-term repercussions on a company's reputation [16, 17, 18]. Conversely, high software quality translates into fewer defects, less technical debt, and higher end-user satisfaction with a software system [4]. As such, it is critical for IT managers to ensure appropriate and ongoing assessment of the quality of their software systems throughout their lifecycle [2, 3, 5, 19]. Yet, software quality is an abstract and multidimensional concept that has been subject to much debate regarding how to define and measure software quality [6, 20, 21].

Some scholars primarily conceptualize software quality through external metrics such as user satisfaction [22, 23, 24], while other scholars have focused on internal characteristics of the source code in terms of structure, complexity, etc. [3, 14, 25]. Industrial standards for software quality, like the ISO/IEC 25000, typically incorporate a combination of external and internal quality characteristics related to functionality, reliability, usability, efficiency, maintainability, etc. [26]. However, continuous software quality assessment based on such standards can be a cumbersome and costly task for organizations with large software portfolios. While project documentation can be helpful, it alone is rarely sufficient for developer teams to maintain a software system [27]. As software systems grow in number and complexity, manual software quality assessment becomes progressively more demanding. Moreover, it is notoriously difficult to balance speed and quality in software development [15]. For instance, if software developer teams feel obliged to deliver demonstrable results in a short timeframe, they can be tempted to employ less rigorous software quality assessments, resulting in a pileup of quality-related challenges later on [28]. Therefore, organizations increasingly turn to SWQATs to provide efficient, effective, and timely quality assessments on a large scale [4, 5, 29].

2.1 What are software quality assessment tools (SWQATs)?

There exists a plethora of commercial and non-commercial SWQATs [6]. Most SWQATs are marketed to organizations with a promise to deliver fast and actionable insights during software development and maintenance [7, 30]. SWQATs are based on a set of characteristics and metrics that form a predefined reference system for their assessments [3]. SWQATs use this reference system to examine source code, detect defects, and measure metrics like lines of code (LOC) or amount of redundancy ("code clones"). Typically, SWQATs then aggregate their results into higher-level quality attributes like maintainability, reliability, complexity, quality in general, etc., and summarize the results in "quality reports" [5, 6].

2.2 The use of SWQATs in IS development and maintenance

SWQATs play an essential role in the IT consultancy industry [3]. For instance, the Software Improvement Group (SIG) relies on SWQATs when advising industrial clients and governmental agencies by turning SWQAT ratings into *"actionable advice using a combination of our technology, scientific methodologies and software engineering expertise to measure, monitor and analyze the source code and architecture of your applications"* [31].

The Chinese company Alibaba – one of the world's largest internet companies and retailers – uses SWQATs for continuous and automatic quality assessment of their software systems since manually assessing their multiple billion lines of code is no longer feasible [8]. SWQATs are applied to enhance efficiency and address the escalating demand for software quality assessments within the company. Now, IT managers at Alibaba use SWQATs to attain *"evidence from an independent assessor and having an external party to announce unpleasant truths (...) [and] to help developers gain reputation from high-quality code written by them"* [8, p. 148].

SWQATs are also used in the public sector. For instance, The Danish Agency for Digitization prescribes a model for portfolio management of central government IT systems [32], which requires all public agencies in Denmark to map the technical state of central government IT systems every three years. This has led the Danish tax agency, the court administration, the municipal IT project organization KOMBIT, and many others to rely on commercially available SWQATs to assess the quality of their software systems [9, 11, 12].

However, while extant literature predominantly highlights the potential of automatically assessing software quality and a large scale [3, 5], it is not evident to which degree the application of SWQATs actually translates into better software quality [33]. Furthermore, research has paid limited attention to the quality characteristics and metrics that form the reference system for contemporary SWQATs. Consequently, little is known about how SWQATs function, what they measure, or how reliable they are as inputs for decision-making.

3. Research method

We adopt a design science approach [34] to guide our research on key challenges of using SWQATs to support decision-making in information systems development and maintenance, and how such tools can be designed to address these challenges. We conduct a technical evaluation of six prominent SWQATs based on Venable et al.'s Framework for Evaluation in Design Science [35]. The evaluation assesses how the SWQATs measure software quality and compares their ratings across different software systems. The results highlight key challenges for using SWQATs and lay the groundwork for designing a solution that addresses these challenges.

3.1 Data collection

We included six popular and widely used SWQATs in our evaluation. SWQAT 1 (Better Code Hub) is developed by a leading IT consultancy firm, the Software Improvement Group, whose clients include DHL, Philips, and KLM. SIG's use of SWQATs has previously been studied in both public and private use contexts [3]. The specific product has since been discontinued after our data collection in favor of Sigrid, a similar SWQAT, based on similar quality model, and produced by the same company [36]. SWQAT 2 (CAST Highlight), is another frequently used and discussed tool [7] developed by the global IT consultancy firm CAST, whose clients include FedEx, IBM, and Coca-Cola [37]. SWQAT 3-5 (Codacy, Codebeat, and Code Climate) are popular SWQATs that are integrated tightly to code hosting platforms like GitHub, to support developers and organizations to continuously assess quality of their products under development. Finally, we included the open-source tool SWQAT 6 (SonarQube) as this tool has been reported to be the most popular tool among practitioners and the most discussed tool in online software developer communities [7]. Taken together, the six tools included for analysis display a diverse array of leading examples of contemporary SWQATs.

For each SWQAT, we collected documentary data sources from official websites, books, and in-tool guidelines. Table 1 provides an overview of the SWQATs in this evaluation and information about their respective vendors.

Table 1: Overview of SWQATs in this evaluation and information about their vendors.

SWQATs	Description	Company	License	Documents
SWQAT 1 (Better Code Hub)	Cloud-based source code analysis service to support building maintainable software.	Software Improvement Group B.V. HQ: Amsterdam	Commercial (Paid individual plan)	Academic studies [3, 36] In-tool + online documentation [38]
SWQAT 2 (CAST Hightlight)	Automatic source code analysis tool that assesses technical debt, complexity, and application size, to improve software quality.	CAST SA HQ: Paris/New York	Commercial (Full access granted)	Online documentation [39]
SWQAT 3 (Codacy)	Cloud-based source code analysis service to monitor code quality.	Codacy HQ: Lisbon	Commercial (Free plan)	Online documentation [40]

SWQATs	Description	Company	License	Documents
SWQAT 4 (Codebeat)	Cloud-based source code analysis service to monitor code quality.	Code quest sp. z o.o. HQ: Warsaw	Commercial (Free plan)	Online documentation [41]
SWQAT 5 (Code Climate Quality)	Cloud-based source code analysis service to assess code maintainability.	Code Climate, Inc HQ: New York	Commercial (Free plan)	Online documentation [42]
SWQAT 6 (SonarQube)	On premise source code analysis service to assess code quality.	SonarSource S.A HQ: Geneva	Open source (Free access)	Academic studies [25, 30] Online documentation [43]

To analyze and compare the SWQATs, we let them assess the quality of six software systems of varying size, functionality, and primary programming language. These software systems are open-source and hosted on GitHub. We gathered the software repositories (source code, documentation, etc.) to create identical versions of the software systems as input for the SWQAT and thereby ensure comparability of results. For each software system, we collected the assessment results from the SWQATs' user interfaces with screenshots. Our reproduction kit [44] includes technical details, documentation screenshots, and links. Table 2 lists the software systems whose quality is assessed by the SWQATs.

Table 2: Overview of the software systems used as input for analyzing and comparing the SWQATs.

Software systems	Description	Programming language
Software system 1: Apache Ignite [45]	High-performance distributed in-memory database management system.	Java
Software system 2: Apache Commons VFS [46]	Virtual File System library.	Java
Software system 3: Apache Airflow [47]	Workflow management platform.	Python
Software system 4: Apache Superset [48]	Business intelligence web application.	Python
Software system 5: Apache CordovaJS [49]	Unified JavaScript layer for Apache Cordova projects.	JavaScript
Software system 6: Apache Echarts [50]	Charting and visualization library.	JavaScript

3.2 Data analysis

We evaluated the SWQATs in four steps. First, we examined documentary data to identify a) how each SWQAT measures software quality in terms of metrics they apply and their unit of analysis, and b) how final assessment results are generated with the underlying software quality model. Second, we let each SWQAT assess the quality of each of the six software systems. Third, we compared the assessment results across SWQATs. To compare SWQATs, we collected which quality characteristics are reported in the final quality assessment reports. We grouped quality characteristics across tools (based on names and descriptions in supplementary material) into overarching categories: Overall product quality, Maintainability, Security, Size, Complexity, and Duplication. For example, SWQAT 2 denotes the overall quality of a system as *"Health"*, SWQAT 3 denotes it as *"software quality grade"*, and SWQAT 4 as *"global project score"*. Since each of these describes the overall quality, we categorized them accordingly and compared the SWQATs along respective quality characteristics, see Table 4. Finally, we condensed the results into the five key challenges that need to be taken into account when using SWQAT in IT management. To address these challenges, we propose a design for tailorable SWQATs that allows for a more conscious, prudent, and context-specific application of software quality assessments.

4. Results

We present the results from our evaluation as five key challenges for using SWQATs in IT management.

4.1 Challenge 1: SWQATs measure source code quality — not software quality

As listed in Table 3, all six SWQATs solely focus on source code as the unit of analysis. This means that they are confined to only assess internal quality characteristics such as the structure and complexity of the source code. Consequently, their assessment completely leaves out external characteristics related to how the software works in its environments, the degree to which a software system meets requirements, data quality, intended usage, etc. Furthermore, the SWQATs neglect configuration files, even though such files can be considered as declarative code that alters systems and their behavior [51]. Likewise, the quality of natural language documents, such as requirements specifications or documentation, is also not assessed by any of the SWQATs. The only exception is SWQAT 6, which to a limited extent measures the frequency of comments in source code. Also, as can be noted in the table, there are substantial differences in the supported programming languages covered in each tool, ranging from 10 to 31 languages.

Table 3: SWQATs' unit of analysis and supported programming languages.

SWQATs	Unit of analysis	Supported programming languages
SWQAT 1	Static analysis of source code	17 languages: C#, C++, Go, Groovy, Java, JavaScript, Objective/C, Perl, PHP, Python, Ruby, Scala, Shell Script, Solidity, Swift, TypeScript, Kotlin
SWQAT 2	Static analysis of source code	27 languages: ABAP, ASP, Bash, C, C#, C++, Cobol, Csh, CSS, EGL, Flex, Fortran, HTML, Java, JavaScript, JScript, Ksh, PHP, PL/1, Python, SQL, TypeScript, VB.NET, VBScript, Visual Basic, XHTML
SWQAT 3	Static analysis of source code	31 languages: Apex, C, C#, C++, CoffeeScript, Crystal, CSS, Dockerfile, Elixir, Go, Java, JavaScript, JSON, JSP, Kotlin, LESS, Markdown, PHP, PLSQL, Powershell, Python, Ruby, SASS, Scala, Shell Script, Swift, TypeScript, Velocity, Visual Basic, VisualForce, XML
SWQAT 4	Static analysis of source code	10 languages: Elixir, Go,Java,Javascript,Kotlin, Objective-C, Python, Ruby, Swift, TypeScript
SWQAT 5	Static analysis of source code	11 languages: C#, Go, Java, JavaScript, Kotlin, PHP, Python, Ruby, Scala, Swift, TypeScript
SWQAT 6	Static analysis of source code	27 languages: ABAP, Apex, C#, C, C++, COBOL, CSS, Flex, Go, Java, JavaScript, Kotlin, Objective-C, PHP, PLI, PLSQL, Python, RPG, Ruby, Scala, Swift, TypeScript, TSQL, VB.NET, VB6, HTML, XML

Usually, the SWQATs function by collecting all files that contain source code in one of the supported languages and parsing their contents into an internal representation, often into abstract syntax trees. From here, the SWQATs perform static analysis, which means assessing the code as written, without actually running it. The static analysis is based on a set of predefined rules to search for patterns in source code that are bad coding practices, error-prone, etc. An example of such a rule is SWQAT 1's *"Write Short Units of Code"*, which identifies functions and methods in source code that are longer than 15 lines of code (LOC). If too many units exceed this number, the rule is violated and reported accordingly. Another example is SWQAT 2's Java code rule *"Switch cases without ending breaks are hard to understand"* [52] which flags all switch statements where case clauses are not finalized with a respective statement. We analyze more examples of such rules and how the SWQATs implement them differently into metrics in section 4.3.

In sum, a key limitation of SWQATs is their restricted focus on static analysis of source code quality rather than providing a comprehensive assessment of the overall software quality of systems in use. While code quality is an essential aspect of software quality, it represents just one dimension of a broader concept. Being unaware of the system’s specific context and requirements, SWQAT may flag code as problematic based on general rules or patterns without considering the unique needs of the application. Consequently, SWQATs operate on a quite narrow and fine-granular basis. While this approach can provide some insights into adherence to coding standards, they are limited in their ability to uncover runtime- and context-specific issues.

4.2 Challenge 2: SWQATs are based on low-level static analysis of single source files and disregard interaction between higher-level components

SWQATs base their quality assessments on low-level static analysis of single files authored in single programming languages. Thereby, they disregard that software systems are often constructed out of many interacting components written in various programming languages, which at runtime, interact via a plethora of protocols. Components are typically considered to be reusable and separately deployable units of software [53].

However, software is usually made up of multiple components composed of multiple files where components interact via a multitude of protocols and technologies. For example, SWQAT 1 assesses the coupling of modules (classes, files, etc.) via fan-in and fan-out of units, i.e., how often a unit is called by others and how often it is calling others. Yet, the metric is not assessed on higher levels of abstraction, such as components or systems. In contemporary software, these are usually the significant building blocks. Just like units, components can be strongly or loosely coupled. However, the static analysis rules of the SWQATs do not identify component interactions. These are difficult to assess automatically since they are often domain and technology specific. For example, components may be implemented in different programming languages using different technologies, where coupling may be introduced by inter-component calls via Remote Procedure Calls (RPC), via calls to REST APIs, etc. All of these are “invisible” to low-level fine-grained static analysis rules that operate on the ASTs of single-language artifacts. More expressive representations of software that capture cross-language and cross-component characteristics would be required to facilitate automatic checks on higher levels of abstraction. Similarly, interactions of components with e.g., databases cannot be assessed via low-level static analysis rules since these cross-language boundaries and since they are often hidden behind multiple technology-specific layers of abstraction.

Similarly, the SWQATs assess complexity on a very low level. Most often, complexity is assessed as the size of components measured in lines of code (LOC) or as the number of linearly independent paths through a program's source code (cyclomatic complexity). Such assessments may not always reflect code quality accurately as highly complex code is not necessarily bad if it's well-structured and well-documented. Furthermore, by only focusing on low-level forms of complexity, SWQATs are unaware of complexity problems that are more coarse-grained than the number of possible execution paths in units. More relevant problems that developers face revolve around the existence of test suites, to which degree they are readily executable, debuggability of systems, e.g., inspectability of running processes, executability of components in isolation, etc. Certainly, the number of technologies, programming languages, protocols, and components of a software system influences its complexity. Yet, such issues are not part of how SWQATs rate the complexity of a system.

The inability to assess a software systems’ interaction between higher-level components can lead to deceptive ratings of important quality aspects. For example, software system 3 (Apache Airflow), which is a workflow orchestration engine that was originally developed by Airbnb [54], receives the worst “cloud readiness”-score from SWQAT 2 (see results in the reproduction kit [44]). This is quite a surprising result since this particular software system is primarily operating on Amazon Web Services (AWS) [55] and Google offers it as SaaS under the name Cloud Composer readily deployed to the Google Cloud Platform [56]. Results like this suggest that the provided rules encode a conception of quality, in this case, cloud readiness, that is not in line with reality.

Thus, our evaluation shows how contemporary SWQATs are unable to assess interactions and dependencies between higher-level components (written in multiple programming languages) that interact with each other via multiple protocols. As a result, SWQATs lack a holistic view of the software architecture and how different parts of the system interact, which is a major limitation in their ability to assess quality characteristics related to system integration, performance, maintenance, and security.

4.3 Challenge 3: Quality models and metrics vary greatly among different SWQATs

As listed in Table 4, SWQATs vary greatly in terms of what is considered to be software quality and how it is assessed. At first glance, the SWQATs resemble each other, as their quality models are often based on classical software quality models, such as the Boehm Model [14] or the McCall Model [57]. For example, SWQAT 1 implements the SIG/TÜViT Evaluation Criteria for Trusted Product Maintainability (SIG, 2020). This model consists of five dimensions—Analyzability, Modifiability, Testability, Modularity, and Reusability from ISO 25010—which are then aggregated into a single overall rating of 'Maintainability'. However, the exact procedure for how this aggregation is computed and which precise parameters are applied is not published. Similarly, for the other SWQATs 2 to 5, only partial descriptions of the proprietary software quality models are publicly available. SWQAT 6's quality model [58] is structurally similar to those of the other SWQATs, but it is the only one in this work that is completely traceable since it is implemented as an open-source tool [59] and extensively documented [60, 61].

Table 4: SWQATs' high-level model of software quality and number of metrics

SWQATs	**High-level Model of Software Quality**	**Number of metrics**
SWQAT 1	Proprietary, SIG/TÜViT Evaluation Criteria [63], inspired by ISO/IEC 25010	10 [36]
SWQAT 2	Proprietary, inspired by ISO/IEC 25010 and ISO/IEC 5055	Disclosed as "more than 325" [64]
SWQAT 3	Proprietary	Disclosed as "Multiple hundreds" [65]
SWQAT 4	Proprietary	10 [66]
SWQAT 5	Proprietary	10 [67]
SWQAT 6	SQALE method [58]	2.587 [44]

While the high-level models for software quality have similarities, the used metrics to vary greatly. Whereas SWQAT 1 relies on only 10 metrics, SWQAT 6 uses 2.587 metrics! Besides the quantitative difference, metrics differ also qualitatively. Metrics that are important in some SWQATs, are not considered to be important by others. A case in point is SWQAT 2's metric *"Javascript in HTML can be unreadable and cause reliability issues"* [62], which checks if an HTML file includes JavaScript code from an external file. None of the other SWQATs implements a corresponding metric or considers such a property to be detrimental to software quality.

Furthermore, while some metrics are common across multiple SWQATs, their implementation can still vary. For example, SWQATs 2, 4, 5, and 6 rely on a rule that checks that "*Classes should not have too many methods*" [68]. Still, the threshold for how many methods per class pose an issue to maintainability is different between the SWQATs. Per default, SWQAT 4 considers that at most 15 methods per class are appropriate [69], for SWQAT 5 it is at most 20 methods [70], for SWQAT 6 it is at most 35 methods [68], and for SWQAT 2 the precise number is undisclosed [71] and varies based on the respective version of the underlying regularly updated quality model. Note, this only illustrates the difference in thresholds that discern these rules.

Since most rules are proprietary, they cannot be inspected more closely to assess to which degree they identify the same source code constructs as methods, e.g., nested methods, methods with differing visibilities, etc. Previous work by Lincke et al. [72] demonstrates that differently implemented static analysis rules that assess the same metric lead to different and non-comparable results.

Similarly, while SWQAT 1, 2, 3, 4, and 6 all assess complexity in terms of cyclomatic complexity, they apply different thresholds. For instance, SWQAT 1 considers units with cyclomatic complexity above five detrimental to quality [36], for SWQAT 3 it is per default 20 [73], for SWQAT 4 and 6 it is 10 [74], and for SWQAT 2 the precise threshold depends on programming languages and is not disclosed [75]. Also, for cyclomatic complexity, it is unclear to which degree the implementations of the SWQATs differ. For example, for SWQAT 6 it is documented which keywords and logical operators of some programming languages are considered when estimating cyclomatic complexity [76]. However, it is unclear to which degree these keywords are suitable to estimate cyclomatic complexity or whether all SWQATs identify the same syntactic elements for the estimation of cyclomatic complexity.

The SWQATs in this evaluation do not only differ in the low-level metrics that they assess. Their quality models differ too, see Table 4. That is, the way in which the results of static analysis are aggregated into higher-level quality assessments is vendor-specific and different between SWQATs. For example, SWQAT 1 simply aggregates results in the form of a compliance ratio, i.e., how many of its ten quality metrics are not violated. For that, it relies on yearly recalibrated distributions of amounts of instances that violate a metric to a certain degree, e.g., at most 43.7% of all LOC are in units larger than 15 LOC, at most 25.2% of all LOC are in units with a cyclomatic complexity higher than 5, etc. [36]. SWQATs 2, 5, and 6 work similarly in terms of how frequencies of violations of static analysis rules are aggregated into intermediate scores, often via arithmetic means, threshold-based mappings, extreme value computations, etc. These intermediate scores are then further aggregated, again often just via computation of arithmetic means, and resulting scores are mapped to discrete ratings using a set of thresholds. These ratings are then presented by the SWQATs in their reports. In some cases, frequencies of violations of static analysis rules are not aggregated directly. For example, SWQAT 5 and 6 associate time estimates with static code analysis rules, which represent an estimate of how long it takes a developer to fix a violation of the corresponding rule (remediation time) normalized by an estimate of total system development time (based on LOC). The sum of remediation times is then mapped to discrete maintainability ratings [60, 67].

Our findings illustrate how contemporary SWQATs apply and aggregate quality metrics differently. Similar results have been reported in previous studies [58, 77]. This stresses the importance of knowing the differences in quality models to make informed choices about which SWQAT to apply in each project, how their results should be interpreted, and their reliability for decision-making. However, as showcased in this study, these insights into how the SWQAT differs are not always easy to access and in some cases, even disclosed.

4.4 Challenge 4: SWQAT ratings are incomparable and inconsistent

As a logical consequence of using different metrics, the resulting ratings are inconsistent and, practically, incomparable between SWQATs. As seen in Table 5, SWQAT results are phenomenologically incomparable since the ratings for various quality characteristics are reported on different scales and with different units. For example, the SWQATs in our study report results using nominal scales, absolute numbers, ratios, or frequencies of occurrences or violations of patterns. Overall quality and maintainability are reported mainly via discrete nominal scales.

However, the number of respective categories is different between SWQATs or the labels of categories are different. For example, SWQAT 2 reports overall quality, maintainability, and complexity on a three-step scale with values low, medium, and high, SWQAT 3 reports overall quality on a six-step scale with values A, B, C, D, E, and F, SWQAT 4 reports overall quality on a five-step scale with values A, B, C, D, and F, and SWQAT 6 reports maintainability on a five-step scale with values A, B, C, D, and E. SWQAT 1 reports maintainability not via a nominal scale but via a ratio of adherence to the ten metrics it uses for assessment. Except for the nominal scales with the same number of categories, it is not clear how reported values can be mapped to one another in a meaningful way.

Table 5: Overview of how the SWQATs rated the software quality of six software systems.

Quality characteristic	SWQAT	Metric name	Results of quality assessments per software system					
			Software system 1	Software system 2	Software system 3	Software system 4	Software system 5	Software system 6
Overall quality	SWQAT2	"Health"	Low	Medium	Medium	Medium	Medium	Low
	SWQAT3	"Software Quality Grade"	B	A	B	B	B	A
	SWQAT4	"Global project score"	n/a	B	A	A	A	B
Maintainability	SWQAT 1	"Maintainability Compliance"	n/a	6/10	4/10	4/10	7/10	5/10
	SWQAT 2	"Agility"	Medium	High	Medium	Medium	Medium	Low
	SWQAT 5	"Maintainability Grade"	C	n/a	C	C	C	D
	SWQAT 6	"Maintainability Rating"	A	A	A	A	A	A
Security	SWQAT 3	"Security"	710	0	291	192	0	0
	SWQAT 4	"Security"	n/a	0	0	0	0	0
	SWQAT 6	"Security Hotspots"	351	19	447	82	7	216
Complexity	SWQAT 2	"Elegance"	Low	Low	Low	Medium	Medium	Low
	SWQAT 3	"Complexity"	2%	0%	1%	0%	0%	1%
	SWQAT 4	"Complexity"	n/a	541	617	783	28	2.430
	SWQAT 5	"Complexity/Code smells"	14.514	n/a	1.479	773	17	1.296
	SWQAT 6	"Cyclomatic complexity",	124.876	4.392	18.057	13.243	666	86.414
		"Cognitive complexity"	113.650	2.945	11.881	7.768	306	249.097
Size	SWQAT 2	"LOC", "Files"	1.342.939 13.057	32.918 512	173.316 1.719	66.259 745	2.436 66	409.484 1.953
	SWQAT 3	"Total LOC"	1 M	41 K	190 K	137 K	3.097	94 K
	SWQAT 4	"Total LOC"	n/a	18.234	14.495	30.097	1.000	59.408
	SWQAT 5	"LOC", "Number of Files"	777.017 9.898	n/a n/a	116.171 1.735	81.846 1.254	1.167 39	71.354 608
	SWQAT 6	"LOC", "Files"	587.518 5.625	23.865 373	185.848 2.145	115.464 1.200	2.467 36	442.376 952
Duplication ("code clones")	SWQAT 3	"Duplication"	2%	3%	13%	11%	6%	n/a
	SWQAT 4	"Duplication"	n/a	65	34	97	2	221
	SWQAT 5	"Duplication"	6.491	n/a	360	699	6	478
	SWQAT 6	"Duplication density",	4.30%	5.20%	2.50%	2.40%	0%	71.80%
		"Duplication Files"	703	36	146	81	0	567

Even in the case of SWQATs using the same scales and units for reporting assessed quality characteristics, results are incomparable since the underlying metrics with associated static analysis rules differ between SWQATs. For example, SWQATs 3, 4, and 6 report assessments of the quality characteristic security via the total number of violations of static code analysis rules that scan code for potential security issues, see Table 5. However, the sets of security-related static analysis rules differ between the SWQATs. Of SWQAT 6's 2.587 static code analysis rules, 142 are security related, whereas SWQAT 3 relies on 58 rules that are enabled by default. The different number of metrics may explain the quite diverse numbers of potential security issues listed in Table 5.

Furthermore, quality assessments are inconsistent across the SWQATs since the results are neither proportional to each other nor are they ordered with respect to each other. Table 5 illustrates that maintainability is assessed constantly to be very good (A rating) for all software systems when assessed with SWQAT 6. However, when assessed with SWQAT 5, maintainability is almost constant on an average rating (C and D) and, when assessed with SWQATs 1 and 2, maintainability ratings vary more and in opposite directions. Software system 2 is assessed to be highly maintainable by SWQAT 2 but to be of average maintainability by SWQAT 1. System 5 receives an above-average maintainability rating from SWQAT 1 but an average maintainability rating (medium) from SWQAT 2, while SWQAT 2 rates system 6 to be of low maintainability whereas SWQAT 1 rates it as averagely maintainable. That is, maintainability ratings are transposed when compared across SWQATs. Another example of inconsistent assessment results can be found regarding security. Here, SWQAT 4 reports no security concerns in code in any of the six software systems (zero violations of static code analysis rules for the software system in Table 5). Hence, the software systems could be considered equally "secure". In contrast, SWQAT 3 finds security violations in software systems 1, 3, and 4, while SWQAT 6 reports security concerns in all of the six software systems. Assessments of the size of software systems are also inconsistent between SWQATs. The reported sizes in lines of code (LOC) differ by factors two to more than 12. For instance, SWQAT 4 reports that software system 3 consists of 14.495 LOC whereas SWQAT 3 reports it to consist of 190k LOC, see Table 5. Additionally, these factors are not proportional between SWQATs.

Finally, for the cloud-based SWQATs 1 to 5, assessment results are incomparable and inconsistent since they are not necessarily stable over time. The assessed quality of even an unchanged software system can change over time when vendors update the underlying quality models, their thresholds, etc. SWQAT users are not necessarily aware of these remote changes since such updates are not always communicated to users.

In sum, the reported results for the quality characteristics in Table 5 vary greatly across the SWQATs. What one SWQAT rates to be high quality, others rate as poor. This does not only highlight how SWQATs ratings are incomparable and inconsistent. It also highlights how SWQATs can produce false positives (identifying issues that are not actual problems) and false negatives (missing real issues). The presence of false results can affect the reliability of decision-making based on tool output.

4.5 Challenge 5: Results of quality assessments with SWQATs can be gamed

Because of the inconsistent ratings, software quality assessments can be gamed by choosing the "right" SWQAT. For example, three SWQATs (2, 3, and 4) aggregate the results of automatic quality assessments into a high-level quality grade, see the first row of Table 4. SWQAT 3 assesses the software systems 2 and 6 to be of top quality (grade A) while the remaining four systems are rated to be of good quality (grade B). SWQAT 4's quality grades appear to be inverted compared to those of SWQAT 3. SWQAT 2 assesses the software systems 2, 3, 4, and 5 to be of medium quality and the systems 1 and 6 to be of low quality. That means that users of SWQATs who are interested in a positive quality assessment of for example software system 6, can choose SWQAT 3 over SWQATs 4 or 2 to receive a "desired" result.

Similarly, users of SWQATs can "generate" favorable assessments for the other quality characteristics such as maintainability, security, complexity, size, and duplications (rows two to six in Table 4) by choosing the "right" tool. For example, the second row of Table 4 lists what SWQATs 1, 2, 5, and 6 assess to be the maintainability of the software systems in this evaluation. Where SWQAT 6 assesses all six systems to be excellently maintainable (A rating), SWQAT 2 only rates system 2 on that level of maintainability. According to SWQAT 2, software system 6 is of low maintainability and the remaining systems are of mediocre maintainability. SWQAT 5 assesses software systems 1, 3, 4, and 5 to be of mediocre maintainability and software system 6 to be of subpar maintainability. For SWQAT 1, software system 5 is the most maintainable (7/10) followed by system 2 (6/10). Software system 6 is rated mediocre (5/10) while systems 3 and 4 receive subpar ratings (4/10). Thus, a wide spread of maintainability ratings can be observed for software system 6. It ranges from an excellent A rating (SWQAT 6) over a mediocre 5/10 maintainability rating (SWQAT 1) and subpar D rating (SWQAT 5), to a worst low rating (SWQAT 2). For the other software systems, the maintainability assessments are more similar but still heterogeneous.

Following our findings, high – or low – ratings of quality in general or certain quality characteristics can be obtained by strategically choosing the "right" SWQATs for the assessment, something for IT owners, planners, and managers to keep in mind when they use SWQAT ratings to support decisions regarding contract negotiations, project terminations, or settling disputes.

5. Towards more tailorable SWQATs

In response to the challenges of contemporary SWQATs identified above, we present five design requirements and a high-level design proposal that allows for more conscious and prudent software quality assessments that better reflect the socio-technical aspect of software systems and the context-specific nature of software quality. For each challenge, we discuss the underlying issue and formulate a requirement that our design for a SWQAT has to support. Finally, we illustrate our design and map the distilled requirements to design decisions.

5.1 Design requirements

The first challenge asserts that SWQATs assess software quality quite narrowly as certain low-level aspects of source code quality. However, software quality is usually more than source code quality. Industrial standards like the ISO/IEC 25000 standard define software quality more broadly as "the totality of features and characteristics of a software product that bear on its ability to satisfy stated or implied needs" [26], which includes quality in use, data quality, etc. Accordingly, machine-readable artifacts like configurations, data, natural language documents, etc. that are often considered key parts of the software too, should be included in assessments related to, e.g., maintainability [51, 78]. This leads us to the first design requirement:

> ***Design requirement 1:*** *The SWQAT should be able to assess quality of more machine-readable artifacts than just source code.*

The SWQATs in our evaluation assess software quality via static analysis of source code separately over files, see Challenge 2. This neglects runtime behavior that has an impact on software quality too. For example, one can think of a distributed software system with formidable source code quality, which may be unusable due to low quality of network connections, an aspect that is invisible in source code and that first can be revealed via dynamic analysis. Additionally, other industrial standards like ISO/IEC 9001 define software quality as the "capability of a software product to conform to requirements" [79] as in ISO/IEC 9001. Conformance to requirements cannot be assessed with static analysis but needs more advanced techniques, such as dynamic analysis in combination with user studies [80]. Consequently, we can identify the second requirement for the design:

> ***Design requirement 2:*** *The SWQAT can ingest results from a wide variety of metrics that measure inputs from sources ranging from machine-readable artifacts to knowledge carried by humans.*

Challenge 3 highlighted that there is significant variation in the software quality characteristics and metrics used by different SWQATs. This inconsistency arises from the fact that SWQATs come with predefined vendor-specific metrics and static analysis rules that cannot be customized beyond merely adjusting various thresholds. This limitation means that users are often unable to tailor the metrics and rules to meet their specific needs, which may result in unreliable or irrelevant results.

Furthermore, the utility and appropriateness of some of the metrics that contemporary SWQATs implement are highly debatable. For example, many SWQATs assess complexity via cyclomatic complexity even though the metric is heavily criticized for its lack of expressiveness and theoretical foundations [81]. To mitigate Challenge 3, we arrive at the third design requirement:

> ***Design requirement 3****: The SWQAT has to support the user in defining and customizing the metrics used to measure software quality. Additionally, it should support the user to precisely specify measurement targets and approaches.*

The results of our evaluation demonstrate that the quality assessments of SWQATs are inconsistent and incomparable, see Challenge 4. The main reason for that issue is that vendors provide predefined, vendor-specific, and non-tailorable quality models with their tools. That is, contemporary SWQATs encode an assumption that software quality can be uniformly assessed over different business domains and types of software. This contradicts extant research that describes software quality to be different depending on domain and perspective [20], and also contradicts industrial standards like the ISO/IEC 25000 series of standards [26] or the SQALE method [25] that suggest to tailor the provided quality model before assessing software quality. Consequently, we describe a fourth design requirement to improve the reliability of SWQATs:

> ***Design requirement 4:*** *The SWQAT has to support the user in defining what software quality is and in customizing the underlying quality model accordingly.*

Finally, Challenge 5 describes that results of quality assessments with SWQATs can be gamed. There are two underlying reasons for this. First, as covered in Challenges 3 and 4, the inconsistencies across SWQAT ratings allow users to obtain different results depending on the tool they use. Secondly, SWQATs lack transparency on how they define software quality and how their assessments, results, and reports are generated. Often, the underlying quality models are only described vaguely in the documentation and the precise metric implementations are rarely publicly available. To mitigate the possibility of gaming results, we describe the fifth requirement as follows.

> ***Design requirement 5:*** *The SWQAT has to be completely transparent in what it considers to be software quality, how it assesses software quality, and how quality ratings, assessments, visualizations, or reports are created.*

5.2 Design proposal

Based on the five requirements above, we propose a high-level design for tailorable SWQATs. Figure 1 illustrates our design as Unified Modeling Language (UML) component diagram. Conceptually, the design consists of three components: The Software Quality Model component that contains an encoded definition of what characterizes software quality for the specific context, the Metric component that implements how certain quality characteristics should be measured, and the Report component that transparently converts the results into suitable presentations.

The Metric component captures both machine-readable artifacts (e.g., source code or documentation) and expert knowledge (e.g., the architecture of a system, deployment processes, or information about how to handle errors in production). In case of measurement of expert knowledge, either that knowledge is transferred into machine-readable documents for which a metric component is implemented or the results of a manual measurement are encoded in a metric component directly. After a quality assessment (time aspect is not illustrated in Figure 1), in which the Software Quality Model ingests all measurement results from the Metric component, it exposes all these and aggregated quality assessments to the Report component, which in turn transparently presents the results as raw data (e.g., the number of violations and occurrences of violations of a static analysis rule implemented in a metric component) or more aggregated data (e.g., overall ratings or visualizations).

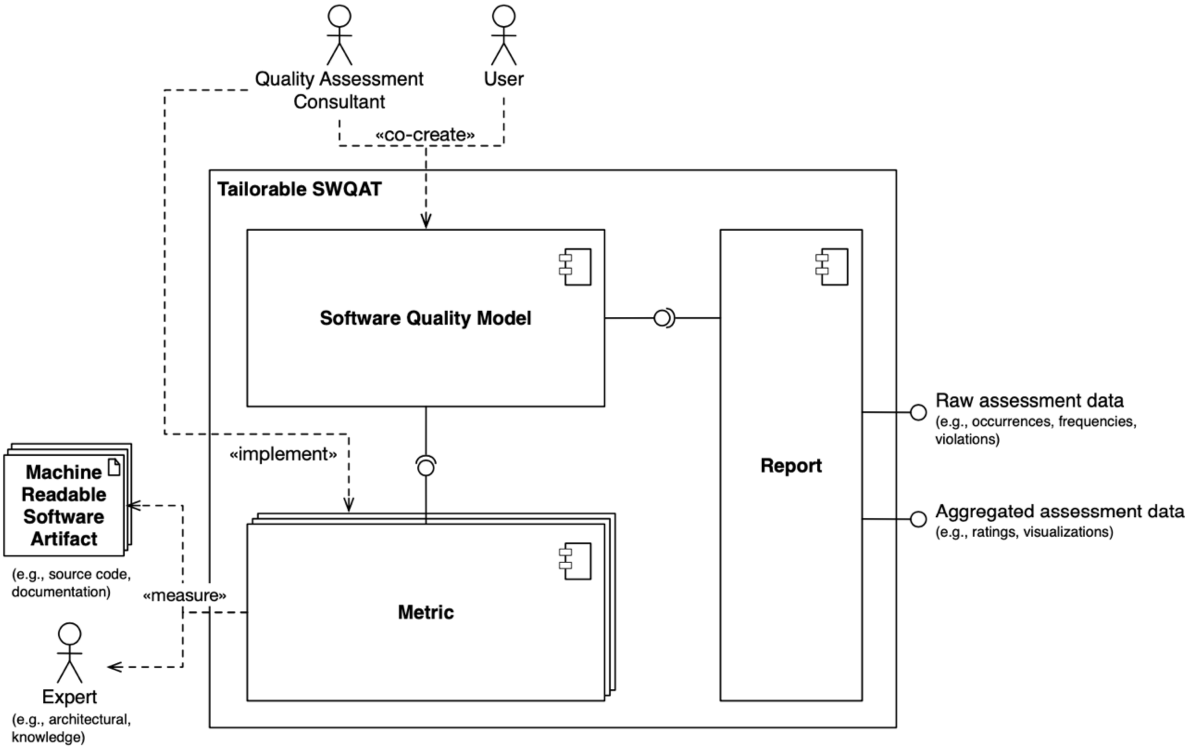

Figure 1: Design proposal for a tailorable SWQAT.

The design denotes three distinct roles or functions that are necessary for the effective functioning of the SWQAT. These roles are referred to as User, Quality Assessment Consultant, and Expert. The User represents the organization that wants to assess the quality of specific software systems. This could be an IT manager or any other person responsible for overseeing the quality of these systems. The User's primary responsibility is to provide input on the software quality requirements, objectives, and constraints to the Quality Assessment Consultant. That is, together with the Quality Assessment Consultant, the User tailors the software quality model. The Quality Assessment Consultant is responsible for encoding the software quality model, implementing respective metrics, and applying the SWQAT to the software systems that are assessed. The consultant can be an employee of the organization itself or an external consultant hired specifically for the purpose of assessing the software quality. The consultant works closely with the user to ensure that the software quality assessment meets the specific requirements, objectives, and constraints of the organization. The third role, the Expert, represents people who have insights into the assessed software and bear knowledge that supplements source code, e.g., on undocumented aspects that are relevant to the assessed software. The Experts' role is to provide data for metrics that are not captured in the machine-readable artifacts.

Overall, the proposed design emphasizes the importance of involving different roles with specific expertise in software quality assessment to ensure a comprehensive and accurate evaluation of the software system. This process is carried out in three steps.

First, the User and Quality Assessment Consultant co-create the software quality model that serves as a reference system for the assessments. This task involves defining what software quality means in the specific context and deciding which qualities shall be assessed and how they shall be measured. By involving both the user and consultant in this step, the resulting quality model reflects the context of the specific software systems that are assessed, addressing design requirements 3 and 4.

Next, the Quality Assessment Consultant implements metrics that either automatically assess certain qualities of software artifacts or wrap the results of (semi-)automatic assessments of certain qualities. This includes input measures from machines and experts, enabling the assessment of qualities that cannot be measured automatically. By doing so, the proposed design addresses design requirements 1 and 2, and expands the assessment beyond just source code in text files.

Finally, the SWQAT converts the results transparently into reports, visualizations, or raw assessment data that is suitable for the user. Transparency is achieved through the active involvement of the user in the specification of what is considered software quality in this context, how software quality is measured, and how the ratings, assessments, visualizations, or reports are created. In addition to ensuring that the SWQAT report is relevant to the specific context, the active involvement also makes the quality assessment process traceable and visible to the user. Thereby, the proposed design addresses design requirement 5.

Being deliberately high-level, our design proposal can be applied differently, depending on project development methods (e.g., agile vs. plan-driven), primary users (e.g., internally by the project team during development or externally by consultants to assess project deliveries), and at various stages of the product life-cycle (e.g., during development or after implementation). For instance, when used by a project team relying on agile software development methods, the tailorability of both metrics and software quality model allows for iterative and incremental assessment of software quality during development. Per development cycle, metrics and quality model may change to reflect changes in scope or requirements following a development iteration [28]. Thereby, quality assessments can evolve together with the software system under development, similar to associated test suites. In plan-driven development metrics and software quality model can be specified up-front, e.g., during contract negotiations with suppliers [see 9,10], to serve as a target that a developed software product has to reach before project end. Similarly, if quality assessments are used for settling legal disputes between suppliers and clients [see 13], contracts and project documentation can serve as basis for tailoring a SWQAT to ensure a more nuanced, transparent, and context-dependent assessment than what contemporary off-the-shelf tools can offer, minimizing the risk of gaming (i.e., selecting a specific SWQAT to ensure a certain outcome).

Taken together, the proposed design allows for a more conscious and prudent application of SWQATs, enabling a comprehensive and accurate evaluation of software systems that better reflect their socio-technical nature. By involving different roles with specific expertise in the software quality assessment process and by tailoring the SWQAT to specific contexts, our design provides a flexible and adaptable solution for assessing software quality. Thus, users in our design are considered broadly to be any stakeholder, including project managers, developer teams, IT departments, lawyers, consultants, etc., that want to assess the quality of specific software systems. With context-specific quality models and metrics, they can use a tailorable SWQAT to assess if a software system is ready for delivery, where to focus maintenance efforts, determine if the quality of the system aligns with the specifications outlined in the contract, and so on. Since the practical implementation of metrics and quality models into a tailorable SWQAT is a technical task that requires programming skills, users in any kind of usage scenario are accompanied by quality assessment consultants that translate a user's software quality concerns into a suitable format for the SWQAT. Thereby, in contrast to the predefined, one-size-fits-all approaches embedded in contemporary SWQATs, the tailorable SWQAT design encourages collaboration between different actors to better reflect software quality as a context-dependent and socio-technical phenomenon.

6. Discussion

The aim of this paper is to advance knowledge on the capabilities and limitations of contemporary SWQATs in information systems development and maintenance, specifically by identifying key challenges and developing a design proposal to address these challenges. Below, we discuss the implications of our results and proposed design before outlining the limitations of our work and suggestions for future research.

6.1 Implications for research

Our research has two implications for research. First, to our knowledge, no prior research compares and critically evaluates how SWQATs assess various software systems. In this regard, the results in this study presents a novel contribution by highlighting several risks with using SWQAT ratings at face value as a basis for decision-making in information systems development and maintenance. As such, our research challenges the predominantly technical-oriented and optimistic literature on SWQATs, which, until now, emphasizes the value of contemporary tools for improving and managing the technical quality of software systems [3, 5, 7, 30]. Since software is a socio-technical artifact and software quality encompasses more than just internal quality characteristics of source code [20], it is very likely that purely automatic assessment of software quality is not practicable, as reflected in the challenges identified in this study. Our design offers an initial conceptual framework for semi-automatic assessments that also includes machine-readable documents other than source code, stakeholder surveys, and automatic measurement of metrics.

Second, although SWQATs receive increasing attention from IT developers, managers, and consultants in practice, research on SWQATs has largely remained within the computer science community regarding software quality metrics [2, 6] or how to develop different types of quality assessment tools [5, 30]. However, as these tools increasingly impact decision-making in various aspects of information system development and maintenance, it is crucial to explore this topic from multiple disciplinary perspectives. Here, IS researchers are uniquely positioned to contribute theory on how SWQATs can be used prudently in different contexts, how various stakeholders understand and apply them, and how SWQAT ratings influence decision-making throughout IT product lifecycles. By highlighting five key challenges to the reliability of using SWQATs in IT management, this article paves the way for new research avenues for understanding the complexities of assessing and ensuring high quality as software systems grow in numbers and sophistication.

6.2 Implications for practice

Since contemporary SWQATs are based on predefined, non-tailorable, and non-transparent software quality models, users of these tools must subscribe to the given vendor's understanding of software quality and trust that the metrics applied are relevant to the specific context. To increase the transparency and reliability of SWQATs, vendors should aim to make metrics, static analysis rules, and aggregation mechanisms as accessible and understandable as possible. To achieve this, SWQAT vendors can incorporate our design proposal to make their SWQATs more tailorable.

It is important to emphasize that our proposed design for tailorable SWQATs does not imply that SWQAT vendors and users should discard their existing quality models and start from scratch with each quality assessment. Instead, we suggest that–in line with industrial software quality standards– for most cases, using a standard quality model as a starting point and then adapting it to the specific context would be a useful approach. This allows for a more efficient and effective tailoring of SWQATs, while still building on established and widely accepted quality models. Furthermore, we envision that the components of tailorable SWQATs can be distributed as open-source, so that software quality assessment consultants can reuse and share previous software quality models and corresponding metrics. A catalog of reusable metrics and exemplary quality models is likely to increase adoption of tailorable SWQATs and make future quality assessments more efficient.

Our suggested design allows for incorporation of human knowledge for software quality assessments. However, the more non-automatic assessments are required, the more cumbersome and resource-demanding it becomes to continuously assess software quality. While a more participatory process initially might be more resource-intensive for the user than procuring and applying non-configurable off-the-shelf SWQATs, we believe the investment will pay off by generating relevant, transparent, and more reliable assessments to inform decision-making. If tailoring a software quality model is not possible due to a lack of expertise or lack of resources, we recommend applying more than one readily available SWQAT at a time and considering the respective results in light of the challenges identified in our evaluation.

6.3 Limitations and future research

Our work has several limitations. First, we conducted a technical evaluation [35] for which we selected six SWQATs to assess the quality of six software systems. It is important to note that the landscape of available SWQATs is constantly changing with ongoing updates to current tools and the launch of new ones. While this dynamic aspect of SWQATs provides limitations to the generalizability of our results, it simultaneously reflects the growing use of these tools in practice and stresses the importance of researching issues related to how they function, what they measure, and how suitable they are for decision-making. Second, we conduct a purely technical evaluation and not a field study. Practitioners may be aware of the shortcomings, inner workings, inconsistencies, etc., between SWQATs when applying them in practice and circumvent these accordingly. However, from our professional experience, we believe this is rarely the case. In the future, we plan to study how SWQATs are applied in industrial practice, which expectations users have towards the results of SWQATs, and how results of automatic quality assessments are operationalized. Finally, further research is needed to evaluate the practical feasibility and potential of our high-level design proposal.

7. Conclusion

Software quality is a fundamental aspect of information systems development and maintenance. It not only ensures the reliability, security, and efficiency of information systems but also plays a crucial role in driving stakeholder satisfaction, cost-effectiveness, and the long-term success of the systems being developed. Organizations increasingly turn to software quality assessment tools (SWQAT) as a new way to manage and automatically assess the technical state of the ever-growing number of large information systems throughout their life cycle. In this paper, we evaluated the reliability of SWQATs for decision-making and proposed a design for how reliability can be improved. Our findings highlighted five key challenges of using software quality assessment tools. First, contemporary SWQATs are based on a narrow and one-dimensional conceptualization of software quality that strictly focuses on source code and leaves out other important aspects, such as the degree to which the systems meet the functional requirements, data quality, or intended usage. Second, SWQATs are based on low-level static analysis of single files and languages and disregard that software systems are often constructed out of many interacting components (written in multiple programming languages) that interact with each other via a plethora of protocols. Third, SWQATs vary considerably with regard to their conception and assessment of software quality. Fourth, software quality assessments are diverse, incomparable, and inconsistent. Five, because of the inconsistent ratings, results of software quality assessments can be gamed by choosing the "right" SWQAT. Taken together, our results cast doubt on the suitability of relying exclusively on SWQATs for decision-making, something for IT owners, planners, and managers to keep in mind when they use SWQAT ratings to support decisions regarding contract negotiations, project terminations, or settling disputes.

To overcome these challenges, we have proposed a high-level design for tailorable SWQATs that enables a more conscious and context-specific application of these tools by more actively involving the user and incorporating a wider variety of metrics that measure inputs from sources ranging from machine-readable artifacts to knowledge carried by humans. Thereby, the design is aimed to better reflect the socio-technical nature of software systems. By allowing users to tailor the assessment criteria and metrics to their specific needs and circumstances, such SWQATs would provide more relevant and meaningful insights to inform decisions about information systems development and maintenance.

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Problems and solutions in adopting information and communication technology in micro and small enterprises

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Abstract:
Micro and small enterprises (MSEs) are predominant worldwide and responsible for the greater employability of citizens, income generation, and production. However, they face resource constraints and rely on information and communication technology to remain competitive, which often causes many problems during or after the adoption process. Knowing the problems that affect micro and small enterprises and the solutions adopted may help other companies face the same issues. In this work, based on a systematic literature review (SLR), we identified and analyzed the problems that occurred during or after the implementation of information and communication technologies in micro and small enterprises and what actions were taken to solve them. We sought to understand the behavior of problems and solutions in the last 21 years and the factors that influenced them. We performed an SLR using the snowballing technique, retrieving 12,936 articles in eight iterations, and selecting and analyzing 105 papers. As a result, we identified 129 problems, divided into 12 categories, and 48 solutions. Such an analysis is advantageous for academia, governments, and business managers, as it allows one to understand problems in advance and formulate more efficient policies, plans, and projects for these enterprises.

Keywords:
Problems; solutions; information and communication technology; ICT; adoption; micro and small enterprises.

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1. Introduction

Small and medium-sized companies (SMEs) are identified as a vital economic sector, contributing to job creation [1][2], innovation, entrepreneurial spirit, and market competition [3-5]. Hillary [4] and Keeffe [6] note that 99.8% of businesses in the UK and globally are SMEs, playing a pivotal role in job creation, internal production, innovation, and productivity growth. Additionally, SMEs provide employment opportunities for women, immigrants, and minority groups [5] and are essential for socioeconomic development, especially in the face of globalization [7] and post-crisis economic recovery [8]. Their adaptability allows them to respond swiftly to market demands and withstand economic challenges [7].

Investing in Information and Communication Technologies (ICTs) substantially benefits small enterprises, improving productivity, operational efficiency, and long-term performance [9-11]. These technologies enhance decision-making, business operations, and small businesses' competitiveness, productivity, and profitability [12][13]. Despite the evident advantages, adopting ICTs in small and medium-sized enterprises (SMEs) faces challenges, including resource constraints, high costs, and a lack of knowledge, which hinder adoption [9]. Nonetheless, the positive outcomes of ICT adoption, such as efficiency gains and cost reduction, remain significant for small enterprises [14]. Therefore, understanding the key factors that influence ICT adoption in SMEs is essential for the growth and competitiveness of small businesses [14].

Several studies analyze factors that influence the success of IT projects. Varajão et al. [15] identify factors impacting IS management projects’ success and classify definitions and measures of IT project complexity. Bezdrob et al. [16] investigate the reasons for the high success rate of IT projects in the Federation of Bosnia and Herzegovina. Other works are limited to identifying problems small and medium-sized companies face when adopting specific ICT tools. Haddara and Elragal [17] identify cost categories and factors for Egyptian SMEs adopting ERP systems. Hasheela-Mufeti and Smolander [18] explore SMEs' challenges when implementing ERPs in Southern Africa. Several literature reviews focus on the adoption of ICTs by small businesses, with some concentrating on specific regions [19][20].

Some studies carry out systematic literature reviews to identify factors that influence the adoption of ICT in SMEs, including work by Ghobakhloo et al. [21], Barba-Sanchez et al. [22], and Rokhim et al. [23]. However, these studies are outdated, and updating the problems faced in adopting ICTs is essential. Our research contributes to this update by highlighting the history of problems and solutions small businesses have faced in adopting ICTs over the last 20 years.

Thus, this study sought to elucidate the challenges faced by MSEs when incorporating ICT and to identify the practices they employ to prevent, mitigate, or transfer these challenges. The findings from this research may serve as valuable insights for academia, government entities, and funding agencies to enhance their ICT procurement, management, and development strategies, as well as their financing and support programs. Specifically, MSEs can better identify project risks and ensure the success of their ICT adoption and utilization endeavors. To this end, we conducted a systematic literature review (SLR) using the snowballing technique and employed descriptive statistics.

In our analysis of 105 articles, this work's main contributions cover identifying the main problems (129) faced by MSE in adopting Information and Communication Technologies (ICTs) in the last two decades and the solutions (48) implemented to resolve them. Furthermore, we delve deeper into the analysis of the problems, carrying out a sectoral breakdown (industry, commerce, and services) and a technological categorization (system, software, and hardware). Furthermore, our study includes a comprehensive mapping of selected works' profiles, examining research methods, data collection approaches, the number of publications in the field spanning 20 years, and the countries where these works were published.

The remainder of this work is organized as follows: Section 2 provides a background on MSEs and their utilization of ICT. Section 3 outlines the research method adopted in this study. Section 4 presents the research findings, while Section 5 discusses the results. Section 6 summarizes our conclusions and outlines avenues for future research.

2. Background

2.1 Micro, Small and Medium-sized Enterprises (MSMEs)

In the literature, the definitions of micro, small, and medium-sized enterprises vary according to annual revenue, number of employees, and other specific factors. Furthermore, these definitions may vary between countries, regions, and sectors [24].

According to the OECD [25], micro, small, and medium-sized enterprises (MSMEs) employ less than 250 people. MSMEs are subdivided into micro-enterprises (less than 10 employees), small (10 to 49 employees), medium-sized (50 to 249 employees), and large ones employing 250 or more people.

In Europe [26], a medium-sized enterprise is defined as a company that employs fewer than 250 people and has annual revenues of up to €50 million and an annual payroll of up to €43 million. A small business is a company that employs fewer than 50 people and has annual revenue or payroll of up to €10 million. A micro-enterprise is a company that employs less than 10 people and has revenues or payrolls of up to 2 million euros.

In the United States, the U. S. Small Business Administration (SBA) defines small businesses by firm revenue (ranging from $1 million to over $40 million) and by employment (from 100 to over 1,500 employees) [27]. These values vary by industry, revenue, and employment and are listed in the SBA Size Standards Table [27]. Micro-enterprise classification is not considered in the United States.

Small and medium-sized enterprises (SMEs) are considered the most crucial sector of the economy because they create jobs [1-3] and are a source of innovation, entrepreneurial spirit, and competition in the market [4][5]. Moreover, they take advantage of individual creative efforts, which makes them vital for a dynamic and healthy economy [4].

Hillary [4] highlights that 99.8% of businesses in the UK are small or medium-sized, which is also the case in other countries worldwide. Keeffe [6] states that these businesses are the majority globally and contribute to job creation and internal production in their respective countries [5]. Groepe [5] adds that they play a crucial role in innovation and productivity growth. Small businesses also create employment opportunities, particularly for women, immigrants, and minority groups [5], and are essential for socioeconomic development, especially in the face of globalization [7] and economic recovery following crisis [8]. Their agility and adaptability enable them to quickly adapt to market demands and withstand economic crises [7].

2.2 Benefits of Investing in ICTs for MSEs

Investing in information and communication technologies (ICTs) can benefit micro and small enterprises as it can help them improve their productivity, manage their operations effectively, and sustain their business performance in the long run [9]. ICTs can also improve decision-making and business operations [10]. Additionally, they play a critical role in improving small businesses' competitiveness, productivity, and profitability [13]. Furthermore, advances in technology that allow for more flexible production methods, downsizing, reorganization, and outsizing by large companies, and the rise of franchising and self-employment will result in more small businesses [4].

Innovation emerges as the key to enduring market challenges [28]. Innovation, defined as "the introduction of new or improved products, methods, processes, and organizational practices" [29], presents an avenue for MSEs to tackle and mitigate the issues they face. In this context, Information and Communication Technologies (ICTs) may be powerful tools to drive innovation and address MSEs' challenges. Carvalho et al. [24] highlight that MSMEs must invest in innovation to compete.

The widespread integration of technology into our daily lives is evident, and MSEs have embraced ICTs to alleviate or circumvent impediments to their growth. In a business context, ICTs encompass a suite of software, hardware, telecommunications, and management technologies, applications, and available devices used to create, analyze, process, store, and transform information [30].

The surge in ICT adoption by MSEs is undeniable. There has been a notable increase in the usage of devices such as smartphones and desktop computers, along with a growing adoption of cloud technologies among businesses [31]. Companies view IT as indispensable for ensuring smooth operations, enhancing customer service, expediting task completion, and attracting and retaining consumers [32]. According to Hassan and Ogundipe [32], for SEs interested in competing, adopting ICT is no longer merely an option.

The benefits obtained by IT adoption by companies of this scale are well-documented. However, as Rozmi et al. [9] highlighted, the adoption process is often hampered by high costs, lack of knowledge, and other internal and external factors.

2.3 Related Works

Several studies analyze the factors that influence the success of information technology projects. For example, in Varajão et al. [15], the authors focus on identifying which factors impact the success of information systems management projects. According to the authors, the results provide researchers and practitioners with a better understanding of IS project management success evaluation. Varajão et al. [15] systematically reviewed the literature to identify and classify definitions and proposed measures of the complexity of Information Technology projects. The article contributes to establishing a common language when discussing complexity and a better understanding of project complexity and its implications for practical IT engineering projects. Bezdrob et al. [16] investigate the circumstances and possible reasons for an unexpectedly high success rate of Information Technology (IT) projects implemented in the Federation of Bosnia and Herzegovina (F BiH).

Several works are limited to identifying problems small and medium-sized companies face when adopting specific ICT tools. Haddara and Elragal [17] identify the various cost categories and factors that could occur when Egyptian SMEs adopt ERP systems. This research provides a list of cost factors and their classifications that can help adopting organizations better estimate required ERP project budgets. Factors related to costs are essential to be considered in SMEs because these companies have restrictions regarding cost. Hasheela-Mufeti and Smolander [18] also explore issues in adopting ERPS. The study's objective is to identify challenges experienced by SMEs when implementing ERP systems and to suggest requirements for achieving successful implementations in SMEs in Southern Africa.

Many of the systematic literature reviews focus on a specific region. For example, Anjum [19] and Chandavarkar and Nethravathi [20] investigate the factors that influence the adoption of ICTs by small and medium-sized Indian companies.

Some works aim to carry out a systematic review of the literature to identify factors that influence the adoption of ICTs in SMEs, highlighting the work of Ghobakhloo et al. [21], Barba-Sanchez et al. [22] and Rokhim et al. [23]. However, these works were already published years ago. An update of this information is relevant to the area. Furthermore, in our work, we highlight the evolution of IT adoption and a history of the problems faced by small enterprises over 20 years. None of the related works have this purpose.

3. Research method

We performed an SLR to identify the problems and solutions encountered by MSEs during the adoption of ICTs. For the selection of articles, we used the snowballing technique. Subsequently, we performed an analysis of the results and applied descriptive statistics.

The choice of this methodology and method offers several advantages. As described by Kitchenham and Charters [33], an SLR adheres to explicit and systematic procedures, ensuring rigor and comprehensiveness in the review process. Snowballing involves leveraging the reference lists of relevant papers and citations within articles to identify additional pertinent literature. This approach allows one to concentrate on seminal works within the field, reducing the noise typically associated with a database search and ensuring comprehensive coverage of related research [34].

As described by Wohlin [34], the initial challenge in employing the snowballing technique is selecting an appropriate starting set of papers, which should encompass articles highly relevant to the research area. Once the start set is defined, each of the selected articles is analyzed. During each iteration, the references cited within an article are examined (backward search), as are the papers that subsequently cited the article (forward search). This iterative process continues until no further relevant work is added to a given iteration. We organized the SLR into three phases: planning, execution, and data extraction. These phases are elaborated upon in the subsequent subsections.

3.1 Planning

During this phase, one lays the foundation for their research by delineating their objectives and devising the methodology that will guide their inquiry. The planning process encompasses the formulation of research questions and the establishment of inclusion and exclusion criteria. The research questions are formulated to obtain the expected results related to the research topic [33].

This work sought to answer the following research questions to understand the problems caused by adopting ICTs and the solutions to solve, mitigate, or transfer them:

RQ1. What is the profile of the works that report problems and solutions?

RQ2. What problems occur during or after adopting ICTs in MSEs?

RQ3. What has been the behavior of these problems over the past 21 years?

RQ4. Do the problems change by industry or section of companies?

RQ5. Do the problems change according to the technology adopted?

RQ6. What are the solutions for these problems that occur during or after adopting ICTs in MSEs?

Wohlin [34] emphasized that before starting the snowballing process, it is necessary to have defined the inclusion (IC) and exclusion (EC) criteria for the snowballing since they will guide the reviewer in including work that meets the review objectives. For the inclusion criteria, we considered the type of work, year of publication, and size of the researched company, among others. We excluded companies with ICT as their core business due to technological bias and the trend towards better technology management, which could distort the results. We defined the following criteria for analyzing the studies that would be included or excluded in the context of the SLR:

Inclusion Criteria:

- The paper was published from 2000 to 2021;
- The title, keywords, or abstract made explicit that the paper was related to the research topic;
- The paper answered at least one of the research questions;
- Work related to IT adoption in MSEs.

Exclusion Criteria:

- The publication was a tutorial, workshop, technical report, or merely an abstract;
- The full text was not available;
- The publication appeared more than once in the reference lists and citations analyzed (duplication);
- Works that considered companies whose main activity was information and communication technology.

3.2 Execution

In the snowballing approach, the second phase begins with the start set. As highlighted by Wohlin [34], no universally correct or highly effective method exists to create this start set. Consequently, one viable approach is to select a well-cited work from a reputable database to form the basis of the start set. Our start set comprised nine works published from 2001 to 2016, all previously meeting the IC and EC. These articles are cataloged as [35] to [43].

Once the start set was established, we started the first iteration, employing backward and forward snowballing techniques. Backward snowballing involves examining the reference lists of the articles to uncover additional relevant works, as shown in Figure 1. In this process, we reviewed the list of references, excluding articles that failed to meet our predefined exclusion criteria.

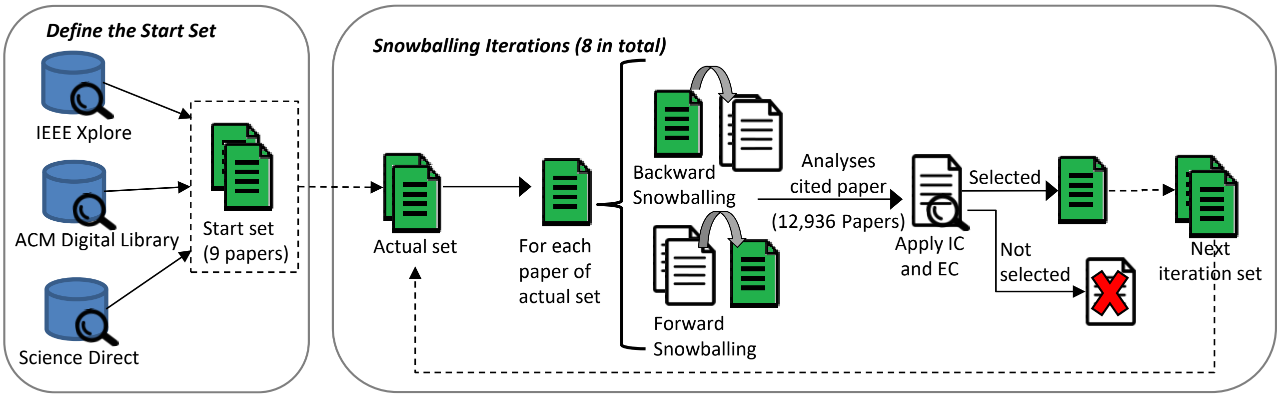

Fig. 1. Phases of the Snowballing Method

Conversely, forward snowballing involves identifying new articles by looking at papers that cite the article under examination [34]. For this, we leveraged Google Scholar's feature for tracking publications that cite a given work.

To assess the selected articles, we performed a comprehensive evaluation process that included the analysis of the titles, abstracts, and results and discussion sections. For the classification of companies in terms of size, we used as a criterion the number of employees established by OECD [25] when available, or we accepted the size (micro, small, or medium) reported in the work. We excluded articles focused exclusively on medium or large size companies. The article search procedures were conducted from January 23 to November 4, 2021. From the start set defined with nine articles, we analyzed 12,936 works in eight iterations and selected another 98 works. In total, our study encompasses the analysis of 105 articles [35-139], each contributing valuable insights to our research.

According to the recommendations of Wohlin [34], one essential efficiency measure in systematic literature studies is the ratio of included articles to the total number of candidate articles examined. We present the efficiency achieved in each iteration of our work in Table 1. To calculate the overall efficiency, we summed the articles included in each iteration, resulting in 105 (9+18+26+22+17+9+3+1+0). Simultaneously, we summed the total number of candidate articles examined in all iterations, resulting in 12,936 (870+1910+3202+3951+2118+661+196+28). The overall efficiency was calculated as the ratio of the articles included to the total candidate articles examined, yielding 0.812%. It is worth noting that efficiency is computed by considering all candidate articles evaluated throughout the study.

3.3 Data extraction

To perform the data extraction, we prepared reading sheets elaborated to capture a comprehensive information set. These sheets systematically collected details such as the title, authors, publication year, country and place of publication, primary research theme, objectives, type, and application context of an article, as well as any other pertinent information that addressed our research questions. Following the tabulation of this data, we applied measures and tools of descriptive statistics, which employs tables, graphs, and summary measures to elucidate and condense data characteristics, allowing a better understanding of their behavior [140].

Table 1. Efficiency

Iteration	Candidates	Included	References	Efficiency	Selected Articles
Start set	-	9	[35]-[43]	0%	8.57%
Iteration1	870	18	[44]-[61]	18/870 = 2.07%	17.14%
Iteration2	1910	26	[62]-[87]	26/1910 = 1.36%	24.76%
Iteration3	3202	22	[88]-[109]	22/3202 = 0.69%	20.95%
Iteration4	3951	17	[110]-[126]	17/3951 = 0.43%	16.19%
Iteration5	2118	9	[127]-[135]	9/2118 = 0.42%	8.57%
Iteration6	661	3	[136]-[138]	3/661 = 0.45%	2.86%
Iteration7	196	1	[139]	1/196 = 0.51%	0.95%
Iteration8	28	0		0/28 = 0%	0.00%
Total	**12,936**	**105**		**0.812%**	

4. Results and analysis

This section highlights the results obtained through the reading sheets according to each research question.

4.1 Profile of the works that report problems and solutions

This section analyzes the profiles of the selected works, considering factors such as methodologies, data collection methods, publication years, nationalities, and industry sectors to answer RQ1. It is important to note that a single study may fall into multiple categories.

RQ1. What is the profile of the works that report problems and solutions?

In terms of the nationality of the selected studies, they were distributed as follows: Brazil, 34 studies (32.38% of the total); South Africa, five studies (4.76%); Kenya, four studies (3.81%); Portugal, United States, and Malaysia, three studies each (2.86%); Finland, Netherlands, Indonesia, New Zealand, Pakistan, United Kingdom, and Australia, two studies each; and Canada, China, Ivory Coast, Egypt, Ethiopia, Fiji, Philippines, India, Iran, Northern Ireland, Japan, Jordan, Nigeria, Norway, Czech Republic, Singapore, Turkey, and Vietnam, one study each. Additionally, 21 studies (20%) did not specify a country (see Figure 2).

Figure 2 illustrates the number of papers published per year. Notably, the average number of articles published from 2012 to 2021 stood at 5.1 per year, while from 2000 to 2010, the average was 3.7 per year. The average number of papers published annually was 4.77, with a standard deviation of 2.95 and a variation of 8.72.

The most used methodologies were the case study and the survey, employed in 22 works (21% of the total), followed by multi-case study (13 articles, 12%), literature review (ten articles, 10%), descriptive studies and action research (six articles, 6%), and field studies (five articles, 5%). Another nine works (9%) used mixed methods, such as surveys, exploratory studies, or grounded theory, while ten others (11%) did not clarify the methodology employed (as shown in Figure 2).

The data collection methods used in conjunction with these methodologies were mostly data triangulation in 37 works (35%), followed by questionnaires in 30 (29%) and interviews in 22 (21%). Another five works (5%) used the literature search or systematic literature review. Eleven studies (10%) did not specify the data collection instrument used.

The selected studies covered a total of 4,469 companies, of which 3,333 (75%) were classified as MSEs by the authors without specifying the size, 371 were micro-enterprises (8%), 579 were small companies (13%), and 186 were medium-sized companies (4%). Medium-sized companies appear in the results because studies focused on small and medium-sized companies were included. However, 17 studies citing only medium-sized companies were excluded.

Of these companies, the service sector was cited in 52 works (49.52%), followed by the commerce sector in 46 papers (43.81%), and the industry in 44 works (41.9%). However, 23 studies (21.9%) did not specify the sector in which the surveyed companies operated, as shown in Figure 2. It is noteworthy that a paper may cite more than one sector.

4.2 Result considering faced issues

To facilitate the grouping of problems identified in the selected works, we developed a set of categories based on the work of Benamati et al. [141]. The selected works mention 129 distinct problems classified into 12 categories. Below is a brief description of each category and the related problems.

Company Management: this category encompasses issues related to company management and IT, such as gaps, needs, and deficiencies in business processes, organizational structure, and business rules.

IT Management: this category addresses problems concerning gaps, loss of control, and deficiencies in IT management and control, including strategic alignment and contracts.

Process and Change Management: this category highlights problems arising from the lack or deficiency of plans, processes, estimates, and controls related to IT and its adoption process.

Workforce: problems related to demands, difficulties, health, skills, and labor-related issues with IT.

Knowledge and Information: issues related to the lack or difficulty of information regarding IT, such as the absence of benchmarks and limited knowledge of IT capabilities.

Timelines and Deadlines: issues like delays and excessively long or short timeframes for adoption, customization, and training. This category suggests that the time spent on IT is a problem.

Costs and Expenses: problems related to IT costs since companies consider acquisition and maintenance costs as issues. Cost-related issues include labor costs, consultancy fees, training expenses, and project cost overruns.

Technical Issues: technical problems occurring within IT. These problems may be caused by or lead to improper use or adoption, and they pertain to more technical aspects of IT, such as security and maintenance, development, IT infrastructure, low performance, errors, and failures.

Adoption: encompasses problems related to the adoption process, including selection, deployment, migration of IT, and adaptations to physical spaces.

Usage: issues arising from the use of IT, such as underutilization, abandonment, system fragmentation, increased bureaucracy, business dependency on the system, and ‘support overload’.

Cultural: cultural issues of the company and its employees related to IT.

Niche: problems caused by IT in relationships between companies and their customers, partners, competitors, suppliers, and consultants. This category also includes a company’s interactions with the government and the judicial system.

These categories are used to answer questions RQ2 to RQ5. Table 2 shows the problems identified in this research grouped by problem category and the works that cite each issue.

RQ2. What problems occur during or after adopting ICTs in MSEs?

When examining the occurrence of these issues, the ‘Workforce’ category emerged as the most frequently mentioned, referenced in a total of 79 distinct papers (75%) (see Figure 3). Following closely, the ‘Technical Issues’ category was the second most cited, appearing in 67 works (64%), while the ‘Costs and Expenses’ category appeared in 60 papers (57%). Conversely, the least cited categories were ‘Company Management,’ with 27 works (26%), ‘Knowledge and Information,’ with 26 (25%), and ‘Process and Change Plan Management,’ with 23 (22%).

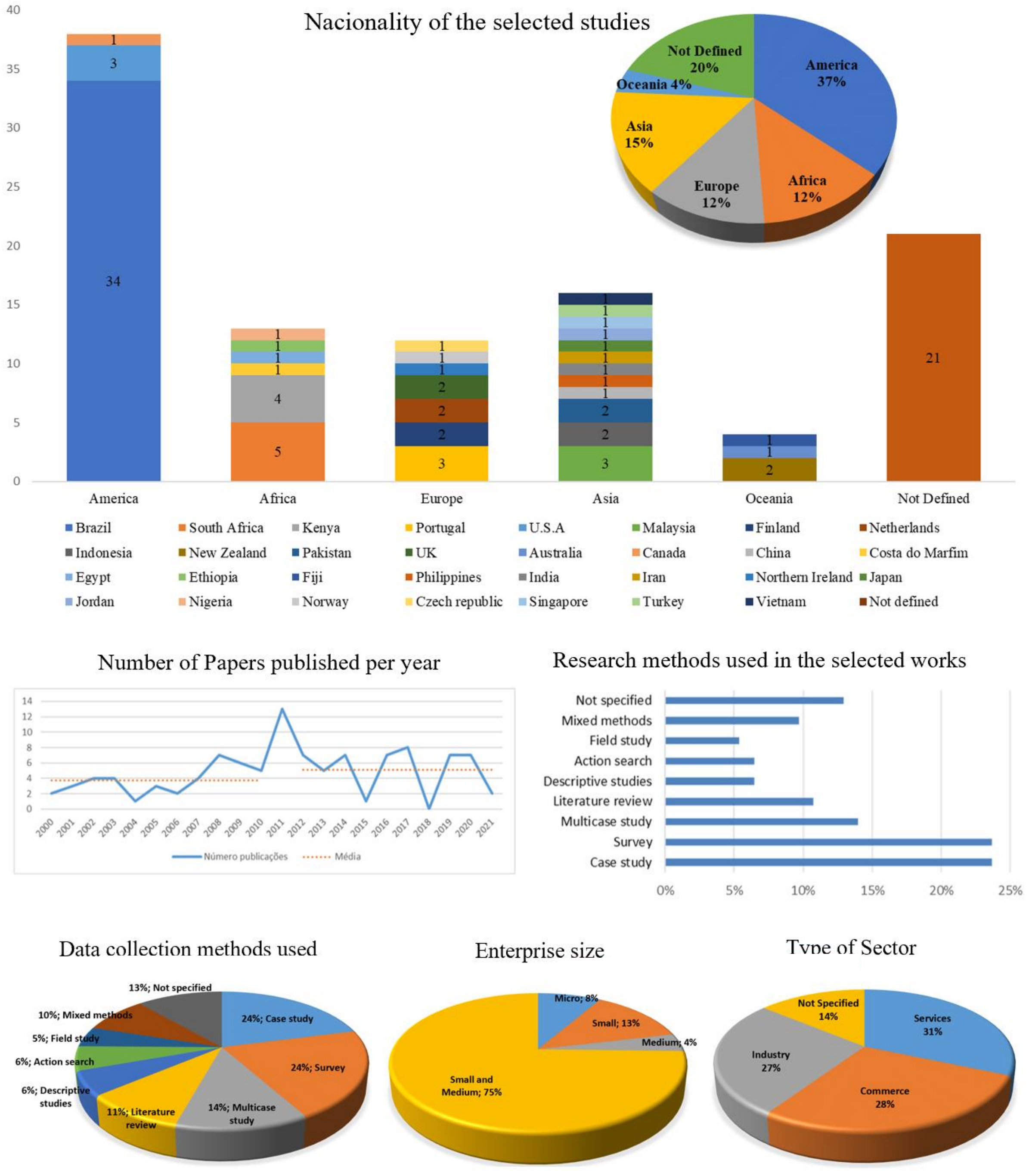

Fig. 2. Profile of the selected works

Table 2. Problems grouped by categories associated with works that cite them

	Problems	Works that cite the problem
Company Management	Unspecified business problems	[37][49][56][67][73][77][85]
	Need to reevaluate/redesign business processes/roles/activities	[35][46][89][91][94][110][122][137]
	Business processes were not well-defined/known	[82][101]
	Need to reevaluate/redesign the organizational structure	[36][37][49][67][77][113]
	Lack of analysis/knowledge about business rules by the company/employee/manager	[83]
	Lack/loss of synergy between departments	[37][67][77]
	Issues involving top management/leadership	[37][67][77]
	IT makes processes overly bureaucratic	[38][79]
	Lack of knowledge about available IT	[36][59][102]
	Lack of access to the latest technologies	[124]
	Lack of clarity in system specifications	[42][73][101][121]
IT Management	Loss of control over IT usage	[58][66]
	Lack or failure of IT usage planning policies	[68][73][75][98][121][126]
	Strategic alignment between IT and the company	[37][56][60][62][67][73][77][110][119][121][137]
	Issues with perceiving or measuring IT benefits	[36][39][47][49][65][86][88][97][100][110][113][129][132][138]
	Management difficulties	[86][121]
	Contractual/SLA problems	[51][82][108][133]
Process and Change Management	Unspecified problems in the development or implementation process	[36][45][49][51][63][79][107][110][139]
	Loss/lack of control over the implementation or development process	[36][45][75][91][92][123][135]
	Lack of IT adoption or change planning policies	[49][85]
	Deficiency in existing IT adoption or change planning policies	[47][48][78][121]
	Issues in selecting team members	[89][123]
	Lack of analysis and alignment of business processes	[47][137]
	Difficulty in estimating project resources	[73][76][91]
Workforce	Employees unqualified in ICT	[35][36][37][45][47][54][56][57][59][61][67][68][69][72][73][75][76][77][78][84][85][86][87][91][98][100][103][105][106][110][114][115][116][118][119][124][125][128][132][133][134][135][136][137][138][139]
	Difficulty in learning the technology	[88][130]
	Lack of training or ineffective training	[48][53][56][60][62][73][77][83][95][117][118][121][126][130][135]
	Employees not participating in training	[98]
	Need for training for the new IT	[35][36][46][49][80][83][88][100]
	Hired company or contractor doesn't know how to provide training	[36][49]
	Lack of employee commitment	[49][59][67][69][77][78][79][82][85][89][90][92][98][99][101][110][121][122][135][137][139]
	Employee resistance	[36][37][38][47][49][54][56][57][59][63][65][67][69][73][75][77][78][79][81][82][85][90][95][103][105][108][110][119][120][121][122][126][127][131][136][137][139]
	Unspecified workforce issues	[36][74][99]
	Employee health problems (RSI, Ergonomics)	[36][37][49][59][67][77]
	High employee turnover	[91][129]
	Employee overload	[36][49][138]

	Problems	Works that cite the problem
	Need for hiring employees	[49]
	Lack of employee or entrepreneur troubleshooting skills	[59][85][133]
	Loss of productivity	[41][53]
Knowledge and Information	Unspecified knowledge and information problems	[40][44][59][92][94][105][113][114][116][128]
	Lack of awareness about IT capabilities	[48][60][62][68][102][106][110]
	Lack of benchmark	[36][49]
	Difficulty in obtaining information about used IT systems	[136]
	Lack of knowledge about the adopted IT tool	[63][65][81][91][109][125]
Timelines and Deadlines	Unspecified time-related issues	[36][38][44][83][84][85][86][93][109][116][130][136]
	Time required to master the new IT	[35][50][105][136]
	Delays in implementation or delivery	[45][47][49][69][83][91][93][117][122][123][137]
	Time for selection and implementation processes was too short	[74]
	Time to implement is very long	[82][99][100][103][108]
	System migration time (long or short)	[108]
Technical Issues	Unspecified technical issues	[121][128][130][132][135][138]
	IT consumes a lot of resources	[104]
	Low performance	[51][53][58][59][93][111][114][129][133][137]
	Software does not meet the company's needs	[41][45][54][79][85][86][88][91][94][102][103][105][106][111][121][127][128][130][131][136][137]
	Lack of quality in internet/phone/power	[59][75][78][104][110][124][132][136][138]
	Unavailability of ICT resources	[78][123][128][132][133][138]
	Unspecified infrastructure issues	[59][61][75][82][85][98][103][106][119][121][132][136][138]
	Issues with data storage	[51][123][128][129]
	Failures, crashes, or errors	[109][111][112][128][129]
	Defect or inconsistency	[92][109][117]
	Documentation problems	[93][111][129]
	Unspecified security issues	[36][37][56][88][128][137]
	Security breaches or failures	[40][49][67]
	Viruses	[40][88]
	Backup issues	[59][66][76]
	IT maintenance is a problem	[102][106][132][138]
	Constant need for customizations due to changes in laws	[108][109]
	Difficulties in customizing IT to meet company needs	[36][41][45][49][55][57][63][71][75][83][100][108][121][123][137]
	Lack of knowledge about business rules by the developer	[75][83][117][125]
	Unspecified difficulties in development and implementation	[56][67][69][73][77][83][90][92][110]
	Issues with system requirement specification	[93][121]
	Lack of technical knowledge in the development team	[75][85]
	Communication problems during the development or implementation process	[53][92][118][135][137]

	Problems	Works that cite the problem
Costs and Expenses	Unspecified cost	[36][37][41][49][56][61][67][72][76][77][85][100][105][112][116][119][128][131][134][136]
	Cost of ICT acquisition	[35][42][44][45][47][50][57][70][71][73][76][82][86][92][102][103][104][106][113][114][128][132][133][135][138][139]
	Cost to maintain IT (technical support)	[38][41][45][75][82][86][87][98][100][104][105][106][110][113][114][124][127][128][131][53][139]
	Cost higher than anticipated	[49][69][91][93][122][137]
	Labor cost	[73]
	Customization cost	[36][42][46][49][55][63][78][100]
	Consulting/support cost	[47]
	User training cost	[38][71][72][82][100]
Adoption	Unspecified integration difficulties	[36][49][69][71][76][88][89][94][103][112][123][128][129][135][137]
	Lack or inadequacy of integration between systems	[96][110][129]
	Incompatibility among technologies	[35][53][76][79][91][93][109][110][128][135]
	Need to integrate the new IT with existing IT systems	[88][121]
	Obsolete equipment	[37][67][77][85][105][115][128][129][134][139]
	Divergence between data structures	[66][117]
	High interdependence among system modules	[63]
	Need for technologies and/or complementary items	[38][46][74]
	Difficulties in purchasing additional items	[48][60][62]
	Wrong IT selection	[76][121]
	Product delivery was incomplete or not carried out	[51][75][93][110]
	System migration problems	[81][117][129][137]
	Installation problems	[76][93]
	Need to redesign the physical environment	[42][43][54]
	Lack of add-ons	[75]
Usage	Underuse of ICT	[35][36][38][48][49][50][51][52][60][62][65][66][68][73][75][78][81][86][97][101][115][127]
	Difficulty in using available resources	[41][45][49][68][69][76][83][88][102][104][105][106][108][111][117][121][126][132][133][138]
	Employee difficulty in adapting to the software	[42][53][82][117]
	Software was abandoned	[39][53][86]
	Lack of technical resources in usage	[73]
	High dependency on the system	[41][63]
	High obsolescence of IT	[36][49][99][100]
	Use of fragmented systems	[50][126]
	Bureaucratic issues	[45]
	Issues with Internet Service Provider	[88][136]
	System redundancy	[59][66][110][129]
	Technical support overload	[91]
	Inefficient or poor-quality technical support	[45][47][51][93]
	Unspecified technical support issues	[94]
	Many updates needed to keep IT operational	[128]

	Problems	Works that cite the problem
Cultural	Unspecified sociocultural issues	[37][55][56][63][67][73][77][81][85][89][105][106][118][132][138]
	Underestimation of IT or lack of trust in system information	[36][47][49][59][75][76][82][86][92][97][133][134][136][138][139]
	Change in working methods	[39][79][117][123]
	Unrealistic expectations	[51][59][97][120][121][125]
	Change in employee relationships with clients or among employees	[36][49][73][127][132][138]
	Increase in internal conflicts or lack of collaboration among employees	[36][49][69][98][101][135][137]
	Conflicts among stakeholders	[73][81][137]
Niche	Partners do not use technology	[136]
	Poor utilization of IT by the client	[86][104]
	Customer resistance	[128]
	Lack of consultants	[36][49]
	Need for external consulting for implementation or usage	[35][37][63][75][83][92]
	Dependency on IT suppliers or consultants	[45][68][71][78][108][128]
	Lack of technical support from the supplier	[36][37][49][56][59][64][67][77][85][92][104][117][121]114[129]
	TIC requires the issuance of tax documents	[36][49]
	Lack of government support and from other agencies	[73][132][134][135][138]
	Legal or judicial problems	[100][106]
	Unspecified issues	[49][73][119][121]

However, when disregarding specific categories, it became evident that the most frequently cited issue among MSEs was ‘employees unqualified in ICT,’ mentioned in 46 articles (44%). This was followed by ‘employee resistance,’ raised in 37 articles (35%), ‘cost of ICT acquisition’, referenced in 26 (25%), and ‘underuse of ICT,’ identified in 22 papers (21%). Figure 4 lists the top 20 problems that garnered the most attention when disregarding categories. Importantly, it is worth noting that articles may address one or more issues. In total, 129 distinct problem items were identified. On average, each of these items was mentioned in 0.9 papers, with a standard deviation of 1.3, indicating a wide dispersion of data from the mean. The variance of 1.75 further underscores this non-uniformity. Indeed, 47 items (36%) were cited at most twice, while only 20 items (16%) received mentions more than 11 times, constituting the top 20 problem items, as depicted in Figure 4.

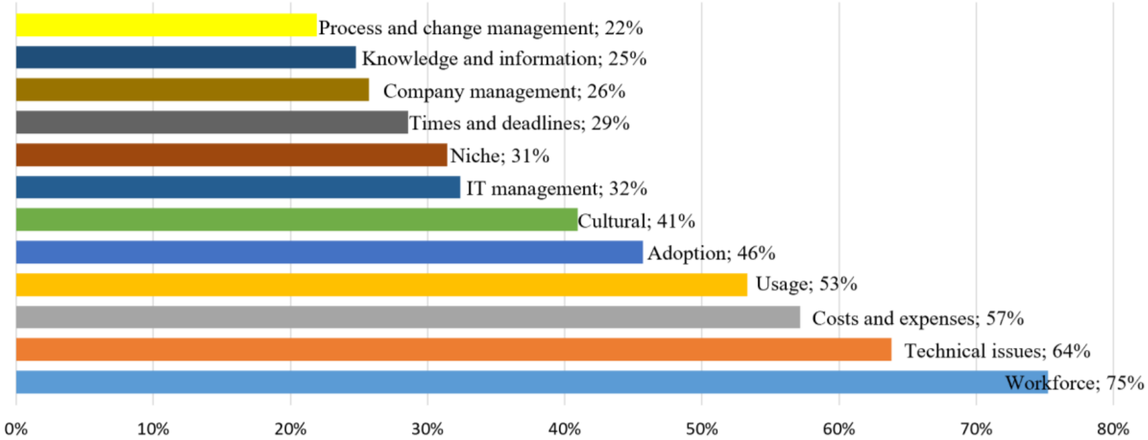

Fig. 3. Percentage of works that mention each problem category

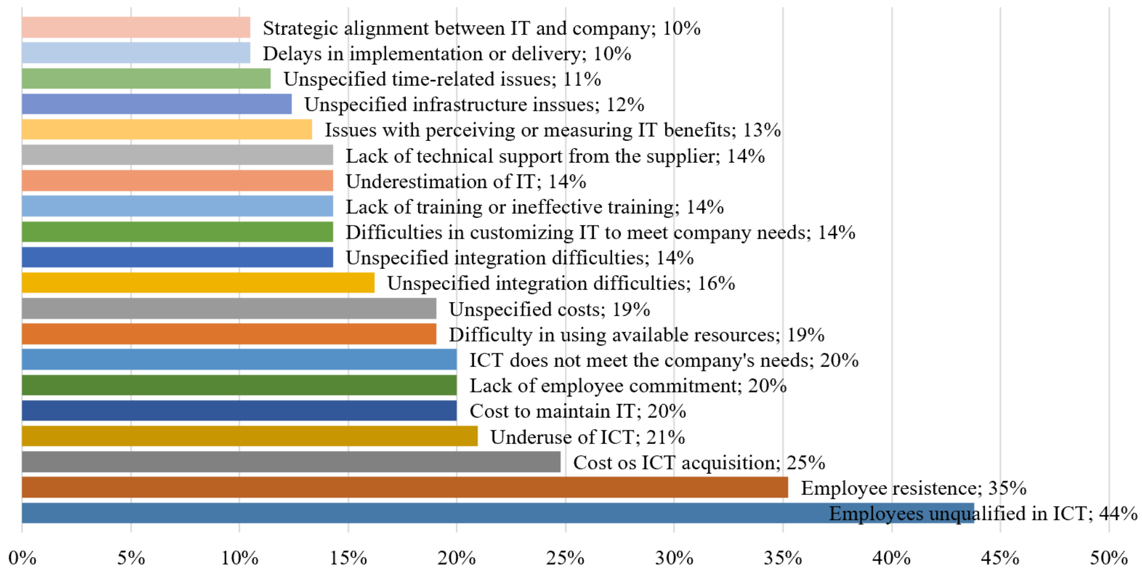

Fig. 4. Percentage of works that mention each issue

RQ3. What has been the behavior of these problems over the past 21 years?

Figure 5 illustrates the occurrence of issues grouped within the predefined categories across the publication years of the works. Notably, there was a substantial variation in category values over the years. On average, the variance among categories was 7.2, with the most significant variations observed in the 'Technical Issues' (17.1), 'Workforce' (16.5), and 'Usage' (11.4) categories. Conversely, the least significant variations were found in the 'Niche', 'Company Management' (both at 1.6), and 'IT Management' (0.4) categories. In terms of standard deviation, the average among problem categories was 2.4. The highest standard deviations were also observed in the 'Technical Issues' and 'Workforce' categories (both at 4.1), followed by the 'Usage' category (3.4). The lowest deviations occurred in the 'Niche' (1.3), 'Company Management' (1.2), and 'IT Management' (0.6) categories. The remaining categories exhibited variations ranging from 10.4 to 2.2, with standard deviations from 3.2 to 1.5.

Figure 6 showcases the categories with the highest occurrence of associated problems in each three-year interval. The most prevalent categories are represented by solid patterns, followed by second-place categories denoted by striped patterns, and third-place categories indicated by dotted patterns.

Consistently, the most cited categories across the years include 'Workforce' (13% to 19%), 'Technical Issues' (11% to 18%), 'Usage' (6% to 14%), 'Costs and Expenses' (6% to 11%), 'Adoption' (6% to 15%), 'Timelines' (11%), 'Company Management' (11%), and 'Cultural' (11%). These findings reveal that the primary categories of IT problems remained relatively stable over the years. However, there was an increase in the significance of 'Technical Issues' and 'Workforce-related' problems in recent years, possibly due to the growing complexity of IT systems and the heightened demand for skilled IT professionals. The outcomes also indicated that specific IT issues were more prevalent during distinct periods, such as problems related to 'Costs and Expenses' during the 2008 financial crisis.

Similarly, the 20 most cited problem items were analyzed across three-year intervals (see Figure 7). The average standard deviation among these problem items was 0.8, with 'employee resistance' (2.5), 'employees unqualified in ICT' (2.4), and 'cost to maintain IT' (2.0) having the highest values. Data variance also showed a significant spread when examining problem items across the studied years, with an average variance of 0.8. The issues with the highest variations were ‘employee resistance’ (6.2), ‘employee underqualified in ICT’ (5.7), and ‘cost to maintain IT’ (4.0). The remaining items exhibited variations of less than 1.9 and standard deviations less than 1.88.

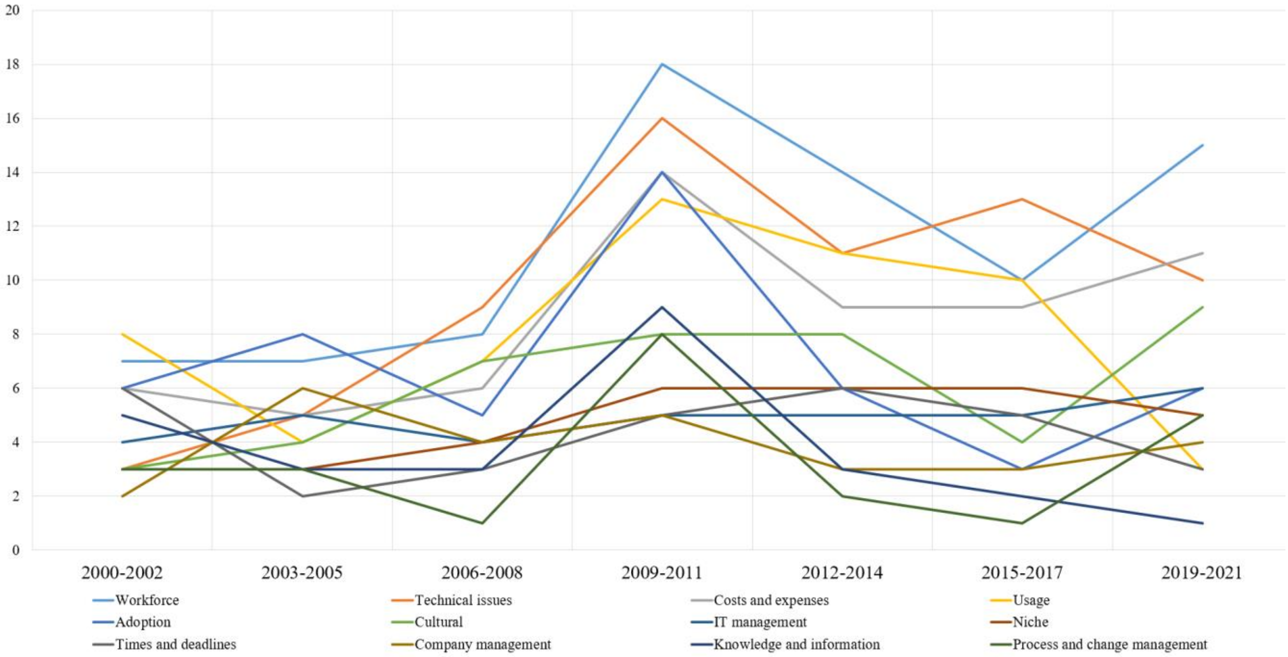

Fig. 5. Number of problems grouped within the predefined categories

RQ4. Do the problems change by industry or section of companies?

The industrial, commercial, and service sectors faced varying problems, each with different intensity levels. Figure 8 displays the top three issues within each problem category, with ‘Unspecified’ referring to studies that did not specify the sector under consideration.

In the industrial sector, challenges encompassed Workforce, Costs and expenses, and Technical issues. The most prevalent issues in this sector were ‘Employees unqualified in ICT’, ‘Employee resistance’, and ‘Acquisition costs’. All categories were mentioned at least nine times, with company management being the least cited, receiving nine mentions.

The commercial sector encountered problems related to workforce, technical issues, and costs and expenses. The most frequently cited issues in this sector were ‘Employees unqualified in ICT’, ‘Employee resistance’, ‘Unspecified costs’, and ‘Acquisition costs’. All categories were represented and mentioned at least nine times.

The service sector faced issues across all defined categories, with the most frequent problems falling into the Workforce, Technical issues, and Usage-related categories. The predominant problem items in the service sector included ‘Employees unqualified in ICT’, ‘Employee resistance’, and ‘Acquisition costs’. However, out of the 114 identified issues in this sector, 34 (30%) were mentioned only once, and 15 (12%) received no mentions.

In papers that did not specify the sector, problems encompassed the categories of Costs and expenses, Workforce, and Technical. The most frequently cited problems included ‘Employee resistance’, ‘Employees unqualified in ICT’, ‘Lack of employee commitment’, ‘Cost to maintain IT’, ‘Software does not meet the company's needs’, and ‘Difficulties in customizing IT to meet company needs’. This group reported problems from all categories with a minimum of four mentions. There were 82 problems (64%) in total, of which 46 (56%) were mentioned once, and 47 (36%) were not mentioned.

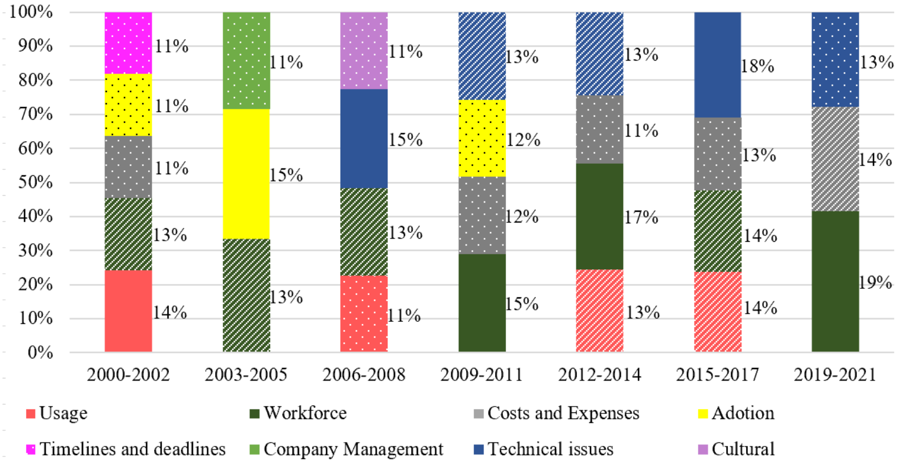

Fig. 6. Predominance of problems by three-year period

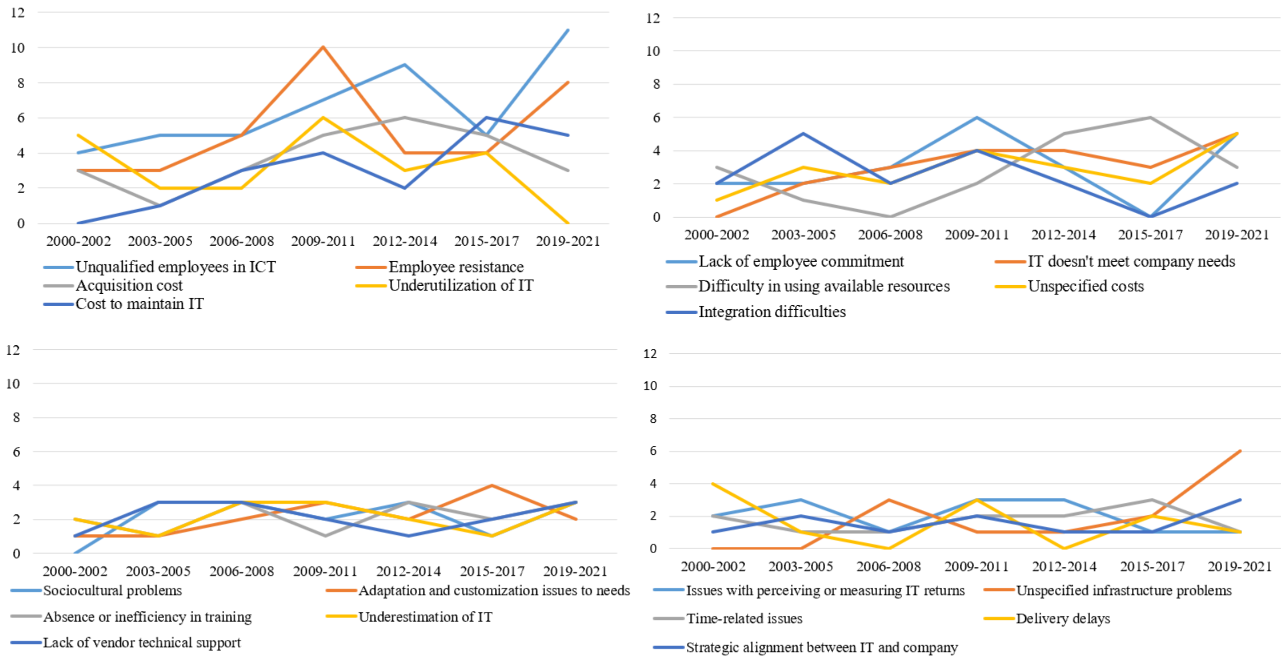

Fig. 7. Problems by Three-Year Period

In summary, the industrial sector faced more Workforce, Costs and expenses, and Technical issues, while the commercial sector primarily grappled with Workforce, Technical issues, and Costs and expenses problems. The service sector encountered challenges in all defined categories. Papers without specified sectors described challenges in the categories of Costs and expenses, Workforce, and Technical issues.

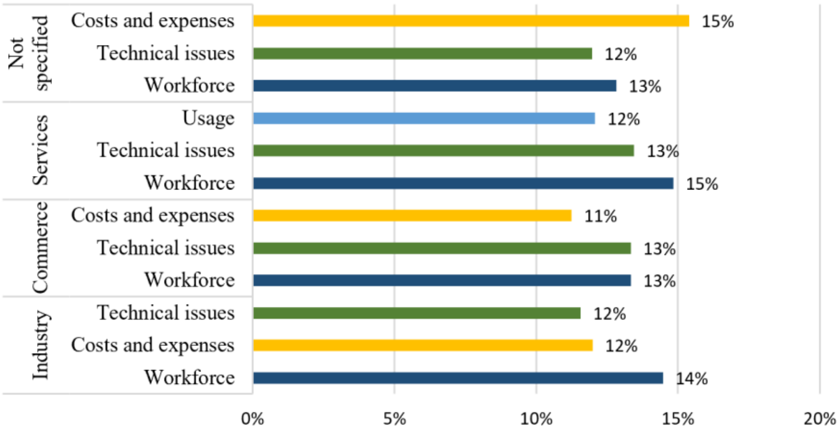

Fig. 8. The three most recurring problems categories in each sector

RQ5. Do the problems change according to the technology adopted?

When relating the researched technologies to the encountered problems, the Workforce category was predominant, cited in 16% of the papers across the three technologies (see Figure 9). When adopting or using software or systems, technical issues often arise due to a lack of alignment with the company's needs and the need for customizations. There may be two causes for this: a natural customization action to align the company and the system with reality or a managerial failure.

Regarding the former, it is a natural process when adopting Enterprise Resource Planning (ERP) systems, as they are often designed to cater to generic solutions rather than companies with unique processes, thus requiring adaptation of the software or system to the company's reality or vice versa. On the other hand, managerial negligence involves not studying the needs of the company and end users, such as not involving employees, suppliers, and managers in understanding precisely what the company requires [142].

Furthermore, usage problems are more prevalent when adopting software or hardware. These issues arise from not fully utilizing the new technology's potential, and the lack of ICT qualification among employees may exacerbate this, especially among older employees [143]. Across all strata, technology-related costs and expenses were a problem, particularly 'Acquisition costs' and 'Costs to maintain IT'. This proved problematic due to the limited financial resources of the MSEs, making them feel the impact of IT acquisition and maintenance costs on their budgets. Similarly, underutilization, redundancy, and difficulty in using IT are other factors contributing to the escalation of IT acquisition and maintenance costs, which significantly impacts MSEs since IT costs appear as one of the main expenses within a company, as observed by Quaresma and Pereira [144]. Thus, there is a significant influence of the type of technology on the problems faced by MSEs when adopting them.

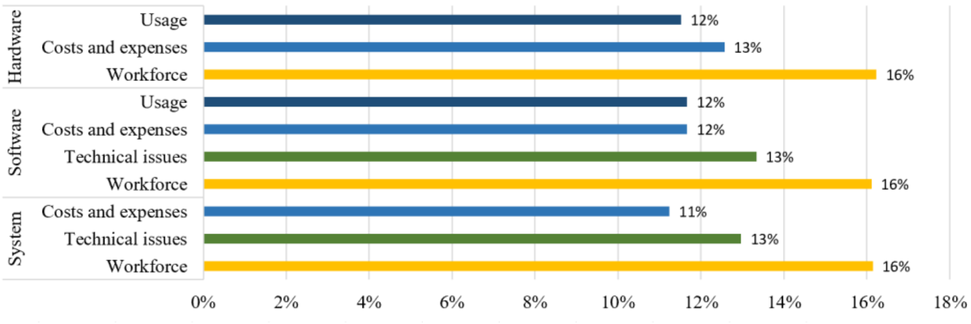

Fig. 9. Problem categories or problem item by type of technology

4.3 *Result Concerning Solutions*

Of the analyzed papers, 19 (18%) described solutions adopted by companies to mitigate, prevent, or transfer the problems they reported. This section discusses such solutions, with the selected works mentioning 48 distinct solutions.

RQ6. What are the solutions for these problems that occur during or after adopting ICTs in MSEs?

Changes in business procedures, especially involving employees, suppliers, and end-users, allow for identifying problems and understanding the needs that ICT must address in a company, avoiding underutilization and fragmentation (see Figure 10). Additionally, providing training and information to maintain engagement has proved to be a good solution to the lack of employee qualifications. This action also allows for a social role for the company, minimizing the responsibility of and waiting for governments to provide these learnings to the workforce. Jahren [145] confirmed that promoting user engagement through communication and information may benefit both employees and companies.

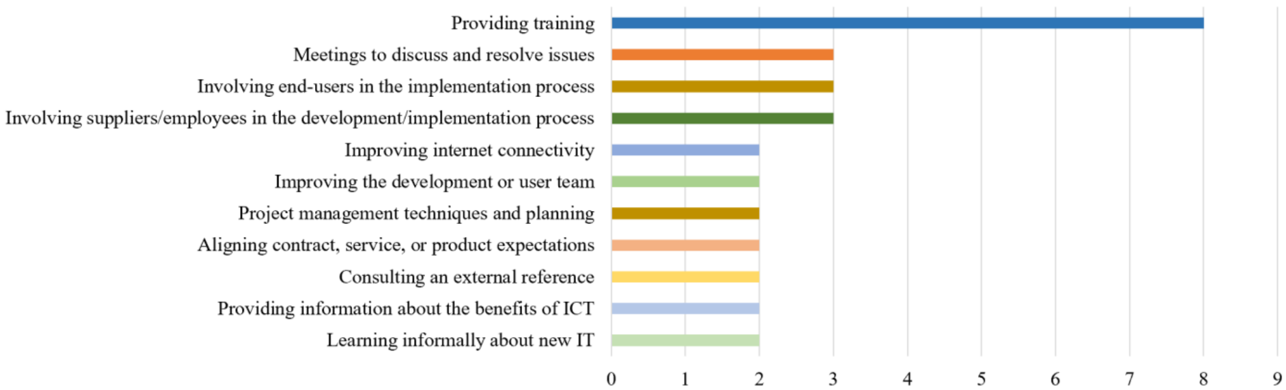

Fig. 10. Solutions when adopting ICTs in MSEs

5. Discussion

We analyzed 105 papers spanning over 21 years, extracting a total of 129 distinct problems and 48 proposed solutions. Notably, the problems displayed variable trends over the 21 years, with limited influence observed based on the type of technology employed or the sector of activity. However, workforce-related issues were consistently prevalent across all analyses.

While a relatively small number of works presented solutions, those that did primarily emphasized adopting new business procedures and providing education and training. Unfortunately, due to the scarcity of data on solutions, it was not feasible to generate significant insights into the evolution of solutions over the studied 21-year timeframe.

Considering these findings, various stakeholders, including managers, government bodies, development agencies, and academia, may take proactive measures to facilitate the more efficient, effective, and less turbulent adoption of ICT in MSEs. Once armed with knowledge of the most recurrent problems, managers may devise strategic plans to preemptively address, mitigate, or transfer these challenges, thus increasing the likelihood of project success. Government agencies may leverage this information to develop more targeted funding and development policies, while academia may explore the myriad opportunities presented by this topic. Through collaborative efforts, these entities may collectively enhance the adoption and implementation of ICT in MSEs.

The case study and survey methodologies proved to be the preferred among researchers. Case studies allow for semi-informal interaction with little control or interference from researchers [146], enabling on-site observation of the ICT adoption and usage process and the collection of valuable data from a researcher's perspective. On the other hand, surveys, which employ questionnaires as a data collection tool, allow for obtaining problems and solutions from the companies' perspective [147].

Most of the research primarily focused on small companies, which could be attributed to their significant representation, accounting for 90% of global businesses, and their acknowledged economic importance as the pillars of their respective economies [9]. There was substantial variation in the publication years of the works, with a noticeable upswing in interest and publications from 2011 onwards.

When examining the problem categories, workforce-related issues, technical issues, costs and expenses, adoption difficulties, and usage problems emerged as the most pressing concerns for MSEs. More specifically, these companies grapple with issues such as the inadequately qualified workforce in terms of both basic and specialized ICT skills, resistance, and lack of commitment from employees averse to change, the high financial outlays associated with procuring and maintaining ICT within their operations, and underutilization resulting from difficulties in comprehending and leveraging the available resources. Additionally, there was a recurring theme of ICT solutions falling short of meeting the specific needs of such companies. These represent the primary categories and problem items encountered by MSEs.

Resistance, costs and expenses, underutilization, and a failure to align ICT with company requirements may be considered moderately serious issues. Employee resistance may substantially impact the overall adoption process, potentially affecting system performance and utilization. Resistance may be rooted not only in concerns about job displacement due to technology but also in factors such as a lack of awareness regarding the benefits of ICT for employee roles and internal cultural dynamics within a company. Marques, Borges, and Almada [148] delved into the factors influencing the resistance or cooperation of entrepreneurs with organizational change, identifying elements like threats to social interactions, peer pressure, and prior experiences. Conversely, underutilization and misalignment with business needs often result from inadequate planning. These issues manifest when managers fail to conduct thorough requirement assessments, neglect to study the technology, or overlook the involvement of end users. These findings align with the research conducted by Wang et al. [6] and Biagi and Rodello [11].

Furthermore, the factors mentioned above may exacerbate the problem of ICT costs in MSEs. Given their resource constraints, these companies are particularly susceptible to the financial impacts of ICT expenditures. Any wastage resulting from underutilization or a failure to meet their specific needs only serves to magnify these cost-related concerns.

Regarding the analysis of problem behavior over the years, no discernible patterns emerged in either the categories or specific problem items. However, workforce-related problems, technical issues, and cost and expense consistently appeared with similar and increasing frequencies despite minor fluctuations over time. This close correspondence in their occurrence rates may suggest an underlying relationship or shared root causes among problems in these categories. Consequently, the shortage of specialized workforce could impede proper installation and utilization, subsequently affecting ICT costs. In line with this, Zhang et al. [142] observed that training and education constitute critical variables that impact the success of ERP implementation in Chinese companies, particularly affecting usage, costs, and overall business performance.

Continuing our exploration of problem behaviors, it became evident that three primary issues persisted throughout the 21-year study period. Workforce-related problems consistently emerged as the most prominent concerns, taking the lead as the second most recurring issue from 2000 to 2008 and 2015 to 2017 and, more notably, dominating as the primary problem during the three-year periods of 2009–2011, 2012–2014, and 2019–2021.

Technical challenges also surfaced as a recurring theme. These problems claimed the top spot in the trienniums of 2006–2008 and 2015–2017, secured the second position from 2009 to 2014, and, most recently, placed third in 2019–2021. Technical difficulties have also been reported as impediments to ICT adoption among micro-sellers in Tanzania [149].

Cost-related issues occurred slightly less frequently, placing second from 2019 to 2021 and third from 2009 to 2017 and 2000 to 2002. Interestingly, this category did not feature as the primary problem in any specific year. Recent research by Mugo [150] in Nairobi highlighted that cost challenges related to hardware, software, internet, training, and support hindered ICT adoption. Similarly, the financial constraints often faced by MSEs render them acutely sensitive to the impact of ICT expenses. Nonetheless, despite these challenges, investments in ICT are often necessary due to the potential benefits they bring to a company. This notion was supported by Ezekiel [151], who observed a changing cost dynamic. In a study involving companies in a commercial center in Dar es Salaam, it was found that costs incurred before the adoption of new ICTs did not significantly affect company performance. However, after the adoption of these technologies, such costs began to have a positive impact on performance.

This analysis underscores the dynamic nature of problems over the years and the recurring relationship among cost and expense issues, technical challenges, and workforce-related concerns. Exploring the influence of technology types on encountered problems revealed minor distinctions among the three categories. Regardless of the technology type, workforce-related issues consistently emerged as the most prevalent, exhibiting equal intensity across these strata. When adopting or employing software or systems, technical problems often surface due to software or systems failing to align with a company’s needs, requiring customizations. This predicament may stem from either a natural need for customization to harmonize the software or system with a company’s specific requirements or from management oversights.

In the case of the former, it is common during ERP adoptions since these systems are frequently designed to cater to generic solutions rather than to companies with unique processes. Consequently, adapting the software or system to a company’s reality and vice versa becomes essential. Conversely, managerial lapses involve neglecting to thoroughly study the company’s needs and the requirements of end users. This omission extends to failing to engage employees, suppliers, and managers to gain a precise understanding of a company’s needs [142].

Usage-related issues tend to surface more prominently during the adoption of software or hardware. These problems arise from underutilizing the full potential of new technology, with the lack of ICT qualifications among employees exacerbating the situation, particularly among older staff members [143]. Across all strata, technology-related costs and expenses emerged as a concern, particularly in acquisition and ongoing maintenance expenses. This challenge proves problematic due to the limited financial resources typical of small companies. As a result, they tend to feel the impact of ICT acquisition and maintenance costs acutely within their budgets. Moreover, underutilization, redundancy, and usability challenges of ICT further contribute to escalating acquisition and maintenance costs. These financial implications substantially impact MSEs, as ICT expenses often constitute a significant portion of a company’s overall expenditures, as noted in studies by Quaresma and Pereira [144]. Therefore, it is evident that the type of technology employed significantly influences the challenges MSEs encounter during adoption.

The solutions most adopted by MSEs to address ICT-related problems include providing training, disseminating information, and fostering learning about ICT. Additionally, involving users, suppliers, or employees in the development and implementation processes, enhancing staff and resource capabilities, and applying management, project, and contract techniques are prevalent approaches.

Introducing changes in business procedures, particularly by engaging employees, suppliers, and end-users, facilitates a deeper understanding of ICT needs within a company. This proactive approach helps mitigate issues related to underutilization and fragmentation. Furthermore, providing training and information emerges as an effective strategy for addressing employee qualification gaps. This action not only contributes to resolving specific ICT challenges but serves a broader social role for the company. It reduces reliance on government initiatives for workforce education, placing the responsibility on the company to uplift its workforce. Jahren [145] provided evidence that fostering user engagement through communication and information dissemination may yield mutual benefits for employees and companies. In summary, the primary solutions implemented by companies encompass a range of strategies to address ICT-related challenges.

Threats to the validity

By adapting the categories proposed by Benamati et al. [141] to classify the problems in this research, we recognize the presence of potential threats to the validity of the work. If these categories are not defined unambiguously or comprehensively, there is a risk of selection bias, as some problems may be interpreted ambiguously and classified inconsistently. However, it is essential to highlight that adopting a categorization minimizes terminological variation, mitigating the use of different terms for similar concepts and reducing the potential compromise of results.

Extracting problems and solutions from work and classifying problems into pre-defined categories are inherently subjective processes. Reviewers' interpretation when applying these categories may introduce discrepancies and bias. Both authors performed the classification to mitigate this threat, and disagreements were discussed. Furthermore, we used descriptive statistics to minimize potential impacts from subjective interpretations when interpreting the results.

Another possible threat is related to the initial set of articles for snowballing. If these articles do not adequately cover all relevant databases, there may be a coverage bias, failing to include essential works. This threat was addressed through careful and extensive research to represent the literature in the start set.

6. Conclusion

Small enterprises play a pivotal role in both economic and social contexts, contributing significantly to their local environments. However, these businesses grapple with competitive pressures and the imperative to survive. To address these challenges, they often turn to ICTs. However, while ICT adoption may offer solutions, it may also introduce new complexities.

Given these considerations, our study aimed to identify the most prevalent problems that MSEs encounter during or after the ICT adoption process and explore the solutions employed to preempt, alleviate, or transfer these issues whenever possible. Our systematic literature review, facilitated by the snowballing technique and bolstered by descriptive statistics, yielded valuable insights.

In summary, our study made significant headway in traversing the existing literature systematically, employing a rigorous methodology to uncover a spectrum of problems and corresponding solutions. We have elucidated the profiles of works dedicated to this subject, delineated primary issues across 12 categories, and distilled the solutions utilized to combat them. Our findings unveiled the nuanced and non-standardized behavior of these problems over 21 years, shining a light on their intricate nature. Importantly, we noted that the sector of activity and the type of technology under study exert limited influence on the problems faced and the solutions implemented.

However, it is essential to acknowledge the limitations of this work. We were unable to segregate problems based on company specifics such as size or sector, as reported in the studies. The interrelationships between these problems also remain unexplored. Furthermore, limitations tied to the snowballing technique arose, particularly concerning the composition of the start set with a predefined set of known works.

Looking ahead, future research endeavors should aim to address these limitations, validate our findings, and delve deeper into the quest for even more effective solutions. By doing so, one may contribute to a more comprehensive understanding of the ICT challenges MSEs face and continue refining strategies for their success.

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Metaverse adoption for the teaching and learning of project management: an exploratory study of student use

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Abstract:
The rapid adoption of collaboration technologies over the course of the COVID-19 pandemic, combined with the advancement, growth, and proliferation of metaverse technology capabilities, has created a heightened awareness and comfort with the use of advanced collaboration technologies for online and distance education. This paper presents an exploratory study of how metaverse technologies can be adopted for the teaching and learning of project management concepts and skills specifically, as metaverses have been identified as a legitimate tool for the support of virtual projects. As a part of this work, a task was designed and adopted in an undergraduate project management course. Study results related to the teaching and learning of project management as well as student perceptions of metaverse technology adoption show that students were able to work together in a metaverse environment and collaborate with one another to achieve group consensus on a task. Ultimately, the findings from this case can guide future adoptions of metaverse technologies both in and out of the classroom.

Keywords:
metaverse; collaborative learning tools; project management and collaboration; project management education.

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1. Introduction

Over the course of the COVID-19 pandemic, there was an increased adoption of collaboration technologies both in and outside of the classroom [1], [2], [3]. In the classroom, we saw the rapid adoption of *Zoom*, *Blackboard Collaborate*, and other collaboration technologies to support online learning and other forms of distance education [4], [5]. Outside of the classroom, we saw the adoption of video collaboration tools like *Zoom*, *Microsoft Teams*, and other metaverse technologies for work as well as for socializing and entertainment [2], [6]. For example, *Loom*, a video messaging company, relied on *Active Replica*'s metaverse technology to host their annual company offsite in 2020 instead of gathering everyone together face-to-face [7] and video game based metaverse *Fortnite* held a virtual concert featuring music artist Travis Scott in April 2020 with over 27 million unique players in attendance [8].

The rapid adoption of collaboration technologies over the course of the pandemic, combined with the advancement, growth, and proliferation of metaverse technology capabilities, has created a heightened level of awareness and more comfort with the use of advanced collaboration technologies. Looking ahead, there is a possibility metaverse technologies will drastically impact the way people collaborate and work together. For example, when summarizing the future of technology in December 2021, Bill Gates stated "within the next two or three years, I predict most virtual meetings will move from 2D camera image grids...to the metaverse, a 3D space with digital avatars" [9]. Furthermore, 43% of business executives already have a metaverse strategy in place according to a survey from Protiviti [10].

With the potential for increased adoption and use of metaverse technologies, it is important to explore how metaverse technologies can be used for education [11], [12]. Research has suggested that the metaverse has the potential to transform education as well as many other industries, including e-commerce, gaming, and currency [6], [12], [13]. Moving forward, it is going to be important for faculty to know how to effectively teach in this new environment and for students to know how to work in and be comfortable learning in this space. Therefore, this research explores the adoption of a metaverse environment for the teaching and learning of project management specifically. The topic area of project management is a suitable discipline to explore as metaverse technologies have been recognized as applicable to the support of global, distributed work and project management [14]. In fact, prior research has found evidence that students find the use of technology and web-based projects created using virtual reality as beneficial to the learning experience in a project management course, suggesting this is a suitable case for more exploration [15].

Therefore, the goal of this work is to explore and learn from the adoption and use of a metaverse technology for the teaching and learning of course concepts in a project management class. To address this goal, this research asks three questions:

(RQ1) Can a task be designed and executed that allows students to work together in a metaverse environment to apply project management class concepts?

(RQ2) Will project management students perceive a sense of presence and collaboration when working together in a metaverse?

(RQ3) Will project management students identify any value from the adoption of a metaverse technology?

To answer these questions, a task was designed and adopted in an undergraduate project management course. This exploratory study presents a course setting and metaverse task design as an example of an innovative application of metaverse use in higher education. Ultimately, the results and findings from this case will guide future adoptions of metaverse technologies both in and out of the classroom.

This paper is organized as follows: The next section presents the background for this research related to metaverse foundations and the application of metaverse technology in education as well as usage in the discipline of project management. The following section presents the research methodology, followed by the results and findings of this work. This research concludes with a discussion, as well as future opportunities for both educators and researchers interested in the adoption of metaverse technologies in education.

2. Background

The background for this research includes a foundational understanding of the metaverse and what metaverse adoption looks like in education in general as well as in the field of project management.

2.1 Metaverse

The metaverse is a network of virtual worlds combining the real world with a virtual world in a seamless way that allows individuals to participate in various life-like activities in a virtual environment [11], [12]. Specifically, a metaverse is defined as "immersive three-dimensional virtual worlds in which people interact as avatars with each other and with software agents, using the metaphor of the real world but without its physical limitations" [16, p. 91].

The term "metaverse" was originally introduced in Neal Stephenson's science fiction novel *Snow Crash* and was used to describe a virtual environment where users interacted as avatars [12], [17]. The term comes from "meta" meaning beyond and "verse" meaning universe [18]. While the topic of metaverses have been studied by researchers and academics in various contexts since then [13], the concept did not gain popularity with the general public until *Facebook* renamed themselves to *Meta* in 2021 [12], [19], [20]. Some predictions suggest the metaverse will become the successor to the internet [11], [12].

One model for research in metaverses identified five key components of interest: 1) the metaverse itself, 2) people and avatars, including concepts of representation, presence, and immersion, 3) metaverse technology capabilities for the support of communication, interaction, and team processes, 4) behaviors such as coordination, shared understanding, and trust, and 5) virtual world outcomes including concepts such as intent to immerse and perceived quality [16]. The decentralized network infrastructure and environment persistence are other important concepts often included in understanding metaverse technology [6], [20].

2.2 Education in the Metaverse

Various theories of learning have developed over time, including the objectivist model, the constructivist model, the cognitive information processing model, the socio-cultural model, and the cooperative or collaborative model [21]. Each of these models vary in many aspects. For example, the objectivist model presents a traditional approach to learning where the teacher passes on information and knowledge to students, while some of the other models, including the constructivist and cooperative models, are more learner focused, proposing students can benefit more from independent or collaborative information discovery [21]. When exploring the adoption of a metaverse environment for teaching and learning, it seems that a student focused learning theory might present an opportunity. In fact, prior research has even suggested that 3D learning environments and environments that support the bundling of various technology capabilities allowing for collaboration, feedback, and student interaction (e.g., multimodal communication tools) are suitable tools for supporting collaborative learning [5].

Cooperative or collaborative models of learning have been used in education in a number of different ways. For example, active learning is a type of collaborative model that focuses on the engagement of students both thinking about and doing things in a learning environment [22]. This type of learning tool has been found by research to be a useful predictor of student success [23]. Another experiential practice in the classroom, referred to as Kolb's learning cycle, specifically asks students to create knowledge through a process of experiential transformation following a four-stage learning cycle that includes abstract conceptualization, active experimentation, concrete experiences, and reflective observation [24]. In a virtual environment, this cycle might ask students to learn through the exploration of concepts, planning for and having an experience, and reflecting on any lessons learned.

As a metaverse environment is an online environment, some of the challenges of online or distance learning may be relevant in this space. For example, online or distance learning challenges suggest students and faculty report a lower sense of engagement, presence, or place, and may report the overall sense of community as lacking [5]. Research suggests when an instructor can create a sense of presence in an online context, increased student engagement and satisfaction with a course and instructor can be achieved [5]. This opportunity is important to emphasize. While leaners may be resistant to turning on their cameras in a video collaboration environment, this would not necessarily be an issue in a virtual world as learners would interact using avatars. Relatedly, prior work recognizes the value of increased student engagement and teamwork in the classroom as a way to prepare students for their future workplaces [25].

Surveys exploring the teaching and learning of virtual collaboration and the adoption of metaverse technology have revealed that not many faculty are using metaverse as a tool for teaching and learning [26], [27], [28]. In fact, a couple of recent surveys reported zero faculty using metaverse technologies for teaching and learning [27], [28]. One contributing factor to this finding may be that the field of education is often considered to be resistant to change [29], however, the domain of digital learning is consistently working to innovate and transform [12]. One systematic review of metaverse education research found that the first study of metaverse education research was published in 2007, with a sharp decline in interest in 2013, and interest returning in 2020 [20].

Overall, researchers have studied metaverse usage in various educational settings including K-12, higher education, and corporate training [12]. For example, one study in higher education used *Minecraft Education* as a tool for teaching Agile concepts, making the case for simulation based learning [30]. Another study in higher education used an open source metaverse environment to bring together interdisciplinary groups of students to collaborate on class projects [31]. A third study exploring metaverse use for corporate training found employees trained in virtual simulations learned faster than classroom learners [32]. In general, these studies have all been supportive of the metaverse as a tool for teaching and learning. Yet, the need for more guidance and best practices remains.

Finally, studies of gamification in education may be relevant to metaverse education research as the environment can be considered game-like. Some studies of gamification suggest these types of techniques can stimulate engagement and deeper learning as students are able to choose their own focus and pace themselves while working through learning exercises [33], [34].

2.3 Project Management in the Metaverse

As mentioned above, metaverse applications have been studied in a number of different contexts [13]. One area of study has been related to virtual world projects. A project is defined as a "temporary endeavor undertaken to create a unique product, service, or result" [35, p. 4]. The goal of project management is to manage the intensive and complex requirements of a project, by employing methods and tools, in order to achieve project success [15], [36]. Project management happens to be a key area of study in relation to metaverse research. In fact, research has found that "virtual worlds have gained legitimacy in business and educational settings for their application in globally distributed work, project management, online learning, and real-time simulation" [14, p. 810]. Furthermore, research has posited that the 3D nature of metaverse technology has much to offer project managers in the managing of large projects [36]. One study illustrated this idea through the development of a project and project plans in the construction of a state in a virtual world to educate and inform individuals about the economic and educational opportunities within the physical state or region [37]. Another study of metaverse project management explored how technology capabilities in a metaverse could contribute to project execution and found a notable benefit of the unique environment emerged through the interplay of social behaviors and technology capabilities, suggesting value in the use of the metaverse for projects [38].

In relation to project management education, research has made the case that it is important for higher education institutions to prepare project management graduates to be ready to work in the current complex field of project management [39], [40], [41], [42]. Education in this area is encouraged by the AIS, ACM, and IEEE and should emphasize both theoretical and practical methods and principles [43], [44]. Project managers need to be prepared with a diverse set of skills including communication, leadership, technical and managerial competencies, and resiliency to manage uncertainty [45], [46]. To address this need, a course in project management is often included in higher education curriculum for students at all levels [47], [48]. In these courses, students are often encouraged to work collaboratively in project teams as well as tasked to learn about project management tools and technologies such as *Microsoft Project*, *Jira*, and various collaboration technologies that can be used to support project collaborations and reflecting on these experiences [40], [48], [49]. Relevant collaboration technologies might include email, video conferencing tools, and even virtual worlds [50] and research has even called for elective coursework to address the use of metaverse tools [51]. Research has found evidence that students value the use of technology and web-based projects created using virtual reality as beneficial to the learning experience in a project management course [15], [52]. This research highlights the importance of technology that supports collaboration among learners, which a metaverse would allow for [15]. Indeed, one early study even used *SecondLife* as a metaverse environment for the teaching and learning of project management [53].

Certainly, the advances in metaverse technologies combined with the increased interest in metaverses will require more faculty to have experience with this type of environment as these tools are used for virtual projects and project management in particular. Therefore, this research seeks to explore if this is possible and if there is a way to design educational experiences that can allow for the teaching and learning of course concepts, specifically in relation to project management, in a virtual world. The following section outlines the details from this case.

3. Research Methodology

This research study looks at the adoption of metaverse technologies for the teaching and learning of project management concepts. The following sections outline the research setting and participants used for this study, the design of the metaverse task, and the data collection and analysis.

3.1 Research Setting and Participants

This study was conducted in an undergraduate level course on project management in Fall 2022. The sample was comprised of twelve students who were split into three teams of four students. Among the participants, six students were male (50%) and six students were female (50%). All but one of the students were college seniors; the one remaining student was a junior. Student areas of study included computer science (17%), data analytics (33%), information systems (25%), or other areas of business (e.g., management, finance) (25%).

As a part of this course, students were studying project management tools and technologies such as *Microsoft Project*, but also collaboration technologies like email, video conferencing, and potentially virtual worlds. As a part of the study of collaboration technologies in this course, an exploration of metaverse technologies and the adoption of the virtual world capabilities for team collaboration was included. Specifically, *Gather* (https://app.gather.town/), a virtual office metaverse launched in 2020, with millions of visitors since then, was selected as the metaverse technology for this exploration.

3.2 Metaverse Task Design

In order to explore the adoption of metaverse technologies for the teaching and learning of project management, students were asked to meet all together in the virtual world (note: this class was primarily a face-to-face class, and the online meeting required a change in modality). The specific areas of focus for this class meeting were communication, team communication, how to enhance team communications, and collaboration technologies that are available for team communication. The class began in the virtual space by meeting as a large group to discuss these foundational concepts (see Figure 1).

Following 20 minutes of background, the students were asked to break into teams and connect with their group in *Gather*. Each team was asked to assume the role of organizational leaders making a decision about the primary collaboration technology to be adopted in their organization. As a part of this discussion, each team member was given a different fact to consider. For example, one team member was told that a calendar feature was a requirement. Another team member was told that video conferencing was not a requirement for the tool but would be an acceptable feature to have. Team members received direct chat messages from the course instructor with these individual requirements. Groups were asked to come to a consensus for their final recommendation and prepare to share and reflect on this task.

Once the task was assigned, students were free to move about the space with their teams to work on their task (see Figure 2). Teams worked together in the virtual world for the remainder of the class as the instructor walked around from group to group to check in.

Fig. 1. Class meeting all together for initial background and instruction

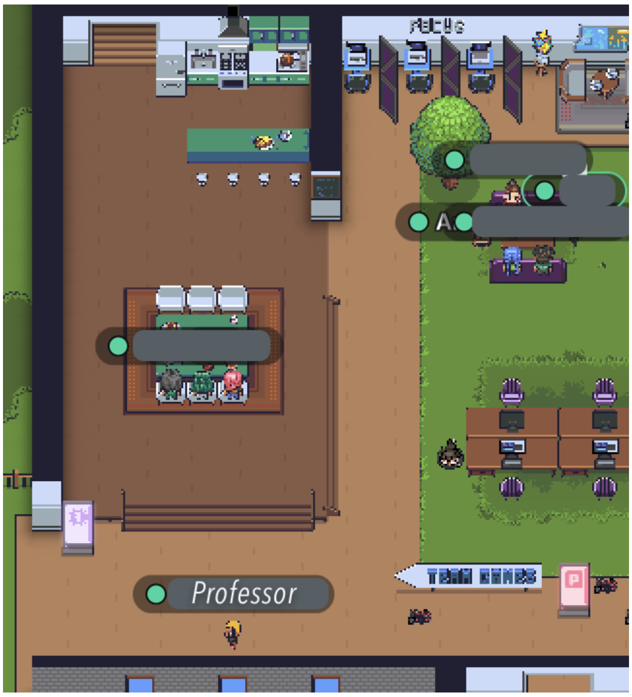

Fig. 2. Team breakout groups with Professor roaming; Team 1 sitting at a table on the deck; Team 2 sitting at a table in the top left grassy area; Team 3 in another area

3.3 Data Collection and Analysis

Upon completion of the task, student feedback was gathered through an electronic survey. Students were asked questions about both the project management task and the technology. Task questions asked students to consider:

1. What collaboration technology did your project management team decide on? Why?
2. Was your project management team able to share information in *Gather*? How so?
3. Did your team make a decision before everyone had shared their individual information? Why or why not?
4. Were you happy with the final collaboration technology that your team selected? Why or why not?
5. Brainstorm three tips for a project manager considering meeting with their team in a metaverse environment.

Technology questions asked students:

6. How strong was your sense of presence (or being there) in *Gather*? (1=not at all; 5=to a great extent)
7. Do you think *Gather* is a useful way to work with other individuals? Why or why not?
8. What technology capabilities did you use in this exercise? What technology capabilities did you not use that you think would have been helpful to have access to?

9. Describe the most positive aspects of the experience you just had? The most negative?
10. Would you recommend using a virtual world for your project management class in the future? Why or why not?

The data captured from this survey was used in evaluation of the findings. As a part of the analysis of the survey findings, open coding was used to look for similarities and differences among the student comments and group the comments into categories [54].

4. Results and Findings

This section presents the findings from this study exploring the use of metaverse technology for the teaching and learning of project management. The following subsections present the research findings related to the teaching and learning of project management and related course concepts as well as student perceptions of metaverse presence and the value of adopting virtual world technologies.

4.1 Teaching and Learning of Project Management

The first research question from this study asks: *can a task be designed and executed that allows project management students to work together in a metaverse environment to apply class concepts?* To address this question a collaborative task was designed that asked students to meet in a virtual world, work through a task where each team member was given a different piece of information, come to a group consensus, and reflect on this experience. Upon completion of the task, students reported that they were able to collaboratively work on the task at hand, share information, reach consensus, and make recommendations for future project managers thus illustrating the application of course concepts.

As outlined above, each team was tasked to assume the role of organizational leaders looking to decide on the primary collaboration technology to be adopted in their organization. Team members were all given different facts to consider in this discussion and were asked to come to a group consensus for their final recommendation. As a part of this exercise, each of the teams selected *Microsoft Teams* as their collaboration technology of choice that would support organizational communication. Student teams reported familiarity with *Microsoft Teams* and determined that it was a match with the each of the individual requirements they were provided. For example, one student summarized their decision by stating:

> "*We decided on Teams since it met all of the requirements we each individually had while we were discussing which platform to pick.*" [P8]

Along with unanimous consensus of the final technology choice, the students also reported unanimous consensus related to their ability to share information with their team members when using *Gather*. For example, one student commented:

> "*Yes, we were able to sit down at a meeting table and have a private conversation about our technology. The chat was also helpful in being able to ask questions in and outside of our group*." [P1]

All of the teams reported that they waited for all of the individual team member information to be shared before they decided on a final technology choice. However, some teams did mention that they brainstormed options throughout their discussion. For example, one student stated:

> "*We gave some suggestions that fit as we went along sharing our information, but we did not decide anything solid until after sharing all of the information*." [P10]

In relation to the metaverse task students were asked to work on, all of the participants reported they were happy with their overall team choice. For example, when asked about their satisfaction with the final collaboration technology selected by their team, one student concluded:

> "*Yes, we all collectively agreed with MS Teams as it was one of the only communication tools we knew that checked off all the requirements*." [P5]

Finally, students were asked to apply the concepts of project management by developing some recommendations and tips for project managers considering meeting with their team in a metaverse environment. Students were indeed able to make some helpful recommendations based on the concepts taught and applied as a part of this metaverse experience. When considering the student recommendations, a few key categories emerged in relation to technology training, meeting practices, task technology fit, and participant motivation. Table 1 is included, summarizing specific student recommendations in each of these areas. A review of the student comments illustrates a clear application of course concepts and overall student learning.

Table 1. Metaverse recommendations for project managers

Category	Student Recommendations (Excerpts)
Technology Training	"*Make sure that everyone knows what the metaverse is and how it works*." [P2] "*Be familiar with the features of the online collaboration space so you know what options are available for use. Many of the platforms have cool features that can go unnoticed*." [P3] "*Training!! Using a new tool can be challenging, especially when there are a lot of features involved*." [P10] "*Establish a backup plan- technology can be unreliable sometimes. Even if your internet is working, some other members might run into problems*." [P3]
Meeting Practices	"*Having an agenda of some kind to help the meeting run smoothly*." [P8] "*Use the chat function to clearly send the main questions or topics so people are able to look over them at any time*." [P11] "*Be responsive once in the metaverse since it is harder to meet when you don't see the persons face*." [P12] "*Having more breakout group activities to get everyone talking*." [P6]
Task Technology Fit	"*Know the audience of your meeting and whether or not this would be something they would like and be interested in because it is more of an informal environment*." [P1] "*Make sure that the metaverse would enhance the meeting*." [P2] "*Consider the number of people who are on your team and whether everyone can fit 'comfortably.' If you are going to have a team meeting with upwards of 25-20 people, I would not suggest this kind of environment because I think it would be too distracting*." [P1] "*If you want people to collaborate in small groups maybe assign groups a meeting space so that they can find each other easily*." [P2]
Participant Motivation	"*Making sure all team members are having input in the discussion and conversation*." [P8] "*Incorporate hands on activities or tasks to encourage engagement. It is hard leading a meeting online especially if nobody has their camera or microphone on*."[P3] "*Maybe a competition to get people into it*." [P6] "*It brings out people's personalities when finding new buttons to hit (ex: the key 'f' threw confetti)*." [P9]

4.2 Student Perceptions of Metaverse Technology Adoption

The second and third research questions from this study are both related to student perceptions. The second research questions asks: *will project management students perceive a sense of presence and collaboration when working together in a metaverse?* To address this question, students were specifically asked about their sense of presence in *Gather*. This question is important as research has suggested when an instructor can create a sense of presence in an online context, increased student engagement and satisfaction with a course and instructor can be achieved [5]. When asked about the feeling of presence in the virtual environment, students reported an average of 4.08 (of 5) suggesting they felt somewhat present in the virtual learning space.

The third research question in this study asks: *will project management students identify any value from the adoption of a metaverse technology?* To address this question, students were asked to reflect on their experience with the virtual environment. In the review of these findings, there were clear student comments suggesting students enjoyed meeting in

Gather. In fact, some student comments showed this tool to be a useful way for creating engagement with the class and class topis. For example, one student commented:

> "*I think this is a great tool because it is more engaging than a Zoom call. You definitely could only use it for a more informal meeting in my opinion because it is a very laid-back setting. I like how I am able to move around too and if I wanted to get an opinion on another group I am able to go into that room and ask them without having to be put in a breakroom by the administrator*." [P1]

The concept of movement in the space and the technology capability supporting individuals walking around was a popular response. Another student stated:

> "*It makes going into "breakout" groups much easier as you do not have to be placed in a room you can just walk around the map and meet with different people*." [P6]

Students also liked that everyone could meet back together after having a breakout team interaction. For example, one student commented:

> "A*t first I was a little confused as to how we would be able to break up in our teams but once I noticed that by allowing teams to venture and sit in different areas it would create its own private room. Which is a great collaboration feature if there are many teams working on a project. Since at the end of the meeting they could all gather together in a main room*." [P7]

Another metaverse capability the students liked was the technology capability allowing for proximity voice and text chat, which is a realistic experience people have. In fact, a few students liked the feature where they could hear team members within their area, with one student stating:

> *"I think it is a unique experience and I really like the feature of having a proximity chat feature where only the members in a certain area of the map can hear you. That way you are free to join other group conversation without hearing all of them at once*." [P8]

Finally, other students found the experience to be a "fun" option for class. For example, one student commented:

> "*Yes, I think that's a great way to work with other individuals because you could get a lot of work done and it's a fun way to work with individuals*." [P4]

Along with the positive feedback, there were some comments that suggested *Gather* would not be a student's first choice of collaboration tools. For instance, one student found the metaverse environment to be difficult to navigate and not very professional, stating:

> "*I think that it would work for some types of meetings but I would not recommend it for just a regular group meeting. The chat function is confusing and hard to navigate. The video chat is glitchy. You can easily accidentally walk out of meetings. It does not feel very professional. It's hard to scroll around the environment and look at your surroundings*." [P2]

Other students echoed the lack of professionalism in a metaverse, suggesting that the metaverse is too much like a game. For example, one student commented:

> "*Gather is fine, however I feel more professional communication tools work better than Gather. This feels like I am playing Pokémon*." [P5]

The gaming capabilities in the metaverse environment were not all perceived as negative. In fact, one student both liked and disliked the overall space. This student commented on both the pros and cons of the metaverse capabilities stating:

> "*Yes- it was fun to do other things in the environment like the Go-karts or play a game. No- it was awkward at times when our team wasn't talking or we would all leave to explore an area and then come back to talk*." [P9]

As a part of the team collaboration and task work, most of the teams reported communicating through the use of video chat, voice chat, and text chat. Some students identified a number of other technology capabilities that were not utilized but mentioned might have been useful. For example, students commented that screensharing, whiteboard features, mini games for team building, or even calendar features would have been nice to use. Some of these students noted that while they did have access to these capabilities, they did not use them.

Student reflection on the overall experiences resulted in both positive and negative comments. Positive comments were related to the technology capabilities that supported communication, flexibility or freedom in the space, group work, and entertainment offered by the tool. Table 2 specifically highlights some of the student comments related to the positive aspects of using a metaverse environment for class and teamwork.

Table 2. Positive student comments

No	Student Comments (Excerpts)
1	"*The freedom of moving around and joining the conversations you want to join*." [P1]
2	"*We were able to chat in just our groups very easily*." [P2]
3	"*Since we could all communicate through voice chat, the decision resulted from a quick conversation rather than a long email chain or different form of collaboration*." [P3]
4	"*Siloed voice room; location accessibility (being at home is comfortable)*." [P5]
5	"*It makes going into breakout rooms very easy*." [P6]
6	"*Easy to access for one and many users*." [P7]
7	"*Using the proximity chat; Being able to explore the map to join other group discussion; audio/video conferencing tools*." [P8]
8	"*It was fun to explore the space and change what we wore as a character*." [P9]
9	"*It was fun being able to mess with the tool after we had our discussion. I also got to try a new tool*." [P10]
10	"*I liked having the class meeting within Gather. It was nice that we could move around and talk with the team members*." [P11]
11	"*It is really entertaining seeing everyone in their avatars in the virtual world. It is a different way to interact than our usual classroom setting*." [P12]

Negative comments were related to the technology capabilities that allowed for navigation of the space, technology challenges, and distractions offered by the tool. Table 3 specifically highlights some of the student comments related to the negative aspects of using a metaverse environment for class and teamwork.

Table 3. Negative student comments

No	Student Comments (Excerpts)
1	"*There aren't really meeting areas with names so it took me a little bit to find my group but not long*." [P1]
2	"*The video chat kept going in and out and the chat was hard to navigate, especially one on one chat*." [P2]
3	"*It makes to harder and slower to go visit each group [in breakout groups]*." [P6]
4	"*Gather could maybe be distracting because of all the features it has with the map and such*." [P8]
5	"*It felt like Zoom or Microsoft Teams*." [P9]

No	Student Comments (Excerpts)
6	"*If you moved out of a space you were disconnected from voice chat*." [P10]
7	"*I did not like when I logged in the avatar was stuck outside of the building and I wasn't able to join the group until I spent time trying to get in*." [P11]
8	"*It was hard to navigate around the set up, my initial log in I was outside the building and couldn't get into the classroom so I had to log out and log back in*." [P12]

As a final point of reflection, the participants in this study were asked whether or not they recommended that future classes be held in a virtual world. Interestingly, 58% of the students were interested in this idea. Some of these comments were related to how engaging the virtual environment was. For example, one student commented:

> "*I personally felt more engaged. I was able to visualize the classroom without being there and to me, that is super helpful.*" [P1]

Students also valued the metaverse as an option for class when other variables would impact the safety of a face-to-face meeting. One student stated:

> "*Yes! If the group can meet safely in person, I think that is best. However, this offers a great alternative because of the features I mentioned above. Many aspects of a classroom can be replicated and members of the class can still collaborate well in a virtual environment*." [P3]

The idea that the metaverse environment offered a close comparison to the physical classroom came up in multiple comments. For example, another student noted:

> "*Yes, I think this would help make the virtual class more realistic. it is still interactive much like a classroom*." [P11]

The students participating in this study have experienced quite a bit of online education over the course of the COVID-19 pandemic and the insights from students with this experience are certainly well-informed. One student noted this as a part of their reflection, stating:

> "*As someone who spent half of their college career online and in a virtual world, I would recommend a virtual class as it is more interactive than just sitting and watch a lecture or staring at someone talking.*" [P5]

Some of the student comments noted that educational experiences in the metaverse would be helpful preparation for future professional experiences. For example, one student commented:

> "*Yes, I would it is necessary to be able to meet in environments like this to get people ready for what some professional experiences will be like*." [P6]

Finally, the entertaining and engaging aspects of the metaverse were identified by students as a motivating reason for metaverse adoption in education. One student noted:

> "*It provides a different, fun way of communication. We have a character we can customize, can move to different spaces, can react to what each other is saying with emotes, and more*." [P10]

While 58% of the student comments specifically recommended the metaverse be used for teaching and learning, 25% of the participants noted that metaverses should be used, but sparingly. These students recommended using a virtual world for class a couple of times per semester. For example, one student commented:

> "*I would only recommend this as a 1 or 2 times thing for class. This because I think a virtual world is pretty cool to use for class, but it could get very distracting at some point for some students*." [P8]

Another student agreed that learning new technologies is valuable but should not be a regular thing, stating:

> "*Yes, but not consistently. It is always good to try new things to keep it interesting*." [P12]

Finally, comments about the suitability of the technology were noted. In fact, one student thought the metaverse might work for some tasks, specifically posters, but not for regular class meetings. This student noted a preference for *Zoom* or *Microsoft Teams* stating:

> "*I think it would work for a poster session but for regular class meetings it seems unnecessary. You can do all of the same things in Zoom and Teams*." [P2]

When asked about metaverse adoption, only one student was not interested in recommending metaverse technologies for teaching and learning. This student summarized their recommendation by stating:

> "*Though it was fun to see what a virtual world could be for a classroom, it would not be as affected for learning since the communication was little.*" [P9]

The feedback from students in this case clearly show the vast majority of participants in this study thought the metaverse should be adopted and used at least sometimes as a part of a student education.

5. Conclusion and future work

This paper explored whether or not there was a way to design an educational experience that could allow for the teaching and learning of course concepts in a virtual world, specifically in relation to project management. A case was presented including the specific task design, process, and student outcomes as well as students' perceptions about the adoption of a metaverse environment as a part of the learning process. The findings from this case suggest that project management students were able to work together in a metaverse environment and collaborate with one another to achieve group consensus on a task. Students were able to reflect on the experience and relate it to the topic of the course as well as reflect on their own perceptions of the experience. Table 4 summarizes both the research questions and findings from this study.

Table 4. Research Questions and Findings

Question	Findings
RQ1 Can a task be designed and executed that allows project management students to work together in a metaverse environment to apply class concepts?	• A collaborative task was designed asking students to meet in a virtual world, work through a task with different information, come to consensus, and reflect • Upon completion of the task, students reported they were able to collaboratively work on the task, share information, reach consensus, and make recommendations for future project managers thus illustrating the application of project management course concepts • Participants reported unanimous consensus regarding their ability to share information with their team members when using the metaverse environment *Gather*
RQ2 Will project management students perceive a sense of presence and collaboration when working together in a metaverse?	• When asked about their feelings of presence, students reported an average of 4.08/5 suggesting they felt somewhat present in the virtual learning space
RQ3 Will project management students identify any value from the adoption of a metaverse technology?	• Student comments suggested they enjoyed meeting in *Gather* and appreciated the engagement, movement, and interaction with the tool • Students expressed some concerns about the game-like features of the tool and lack of professionalism • Overall, 58% of the students were interested holding future classes in the virtual world

The contributions of this work are several. First, a task, the technology, and teaching process is presented for the teaching of project management concepts in a virtual world. Second, tips for future project managers are included as the outcome of the student work (see Table 1). Student perceptions and recommendations related to metaverse presence and the use of collaboration technologies for projects are also presented. Finally, this research provides support of the adoption and use of metaverse for the teaching and learning of project management as students in this project were overall satisfied with the technology usage as a possible learning tool.

The limitations of this work present additional opportunities for educators and researchers. First of all, the number of participants in this study was small and may be considered exploratory. However, prior research has concluded qualitative research with twelve participants is enough to reach data saturation [55]. It is also important to note that the class, the instructor, and the teams, had established relationships prior to having this experience. This class exercise took place following the semester midterm, so each of the groups had already spent time working together. Therefore, in this case, the teams and the instructor had already established relationships and this experience might not have been as successful if teams were brought together to work in the metaverse without the foundational relationships formed prior to the virtual experience. Future research should explore metaverse adoption in larger class sizes and more random team pairing to determine what type of impact these factors may have. It is also important to note that the participants in this case were students from an undergraduate-level course on project management, and they may have different characteristics from the general population.

As with most digital learning innovations, technical issues are a potential challenge. In this study, the faculty member did have to change the administrative settings of the browser to be able to share the instructor screen. This last-minute challenge took away from some of class time. In fact, one student commented on this issue as a negative: "*the professor needing to leave and join the room to use the screen sharing feature*" [P7]. However, it is important to note that there were not any student technical challenges with the technology reported in this case. In an effort to catch any possible issues ahead of time, the class did log into the virtual classroom in advance of the virtual class meeting time, just to make sure everything would work when the time came. Of course, faculty should always prepare for these types of issue and perhaps have a backup plan in place (e.g., *Zoom*, or a university supported virtual meeting tool). Relatedly, the technology choice in this study is also a limitation as *Gather* is only one example of a metaverse technology with unique technology capabilities that are not representative of all metaverse technologies.

One of the research questions in this study specifically explored the student perceptions of presence and found that students did feel somewhat present in the metaverse. This question is especially important due to the impact of presence on course engagement and satisfaction from students [5]. While it seems like the findings in this case were valuable, it would be interesting to compare the sense of presence when in a *Zoom* meeting or another collaboration tool to a virtual world meeting, especially when considering the lack of cameras on when teaching in many virtual collaboration platforms [5].

Finally, while the task from this study was specifically related to the discipline of project management, future work might consider applying this type of collaborative task in other classes. For example, teams could be asked to collaborate on other topics, e.g., given a task to identify a solution, challenges, or opportunities, with individual students provided with unique requirements that would need to be shared so that collaboration in the metaverse is essential to the task. As more educators begin to experiment with metaverse technologies for teaching and learning, more support for the technology, lessons learned, and best practices will emerge.

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Biographical notes

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