

# Understanding End-User Challenges in Digital Construction Information Management

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**Abstract:** The construction industry relies heavily on effective communication and collaboration to manage complex, unique projects, but often faces challenges due to fragmented information and poor data management practises. This paper aims to answer the question of what the key barriers end-users face are when managing information during the construction phase and how these can be effectively assessed and addressed. The study uses a multi-phase approach that includes a comprehensive literature review, the 5M (Manpower, Methods, Machinery, Materials, Management) categorisation framework and the AHP (Analytic Hierarchy Process) method, supported by survey data to validate and prioritise the identified barriers. The research found that the main barriers for successful implementation of Common Data Environment (CDE) systems are the use of multiple communication channels, low awareness of the benefits of CDE and insufficient user training and digital skills. These findings are of critical importance for construction professionals, project managers and policy makers looking to improve collaboration, reduce inefficiencies and promote digital transformation in construction projects. The findings encourage future research into targeted training programmes, unified communication protocols and awareness campaigns to improve the uptake of CDE systems and promote a more integrated and efficient construction industry.

**Keywords:** analytic hierarchy process (AHP); building information modelling (BIM); common data environment (CDE); communication in construction

## 1 INTRODUCTION

The digital transformation represents one of the most significant paradigm shifts in modern construction practice, with far-reaching implications for global infrastructure development, economic productivity and environmental sustainability. As the construction industry embraces the principles of Construction 4.0, the integration of digital technologies has become not only a competitive advantage, but a fundamental necessity for project success. The transition to digitalisation goes beyond the mere introduction of technologies and leads to a fundamental transformation of organisational structures, operational processes and professional identities.

The evolution of construction practices towards Construction 4.0 is characterised by the widespread adoption of sophisticated digital technologies, including Building Information Modelling (BIM) and Common Data Environment (CDE). Within this digital ecosystem, CDE has emerged as important platform that facilitates the centralised exchange of information and optimised collaboration between the various project stakeholders. These systems serve as the backbone of modern construction workflows and integrate data from various sources, including specialised software applications, drone surveys and intelligent construction machinery. As highlighted in the literature, the effective implementation of CDE requires a comprehensive digital strategy that guides organisational change and aligns technological capabilities with strategic objectives. However, the successful deployment of these systems is critically dependent on human actors who must navigate complex workflows and adapt to new paradigms of collaboration in team-based environments.

Despite the technological sophistication of modern CDE platforms, their effectiveness in the real world is limited by significant human and organisational factors. The digitalisation of construction companies requires fundamental behavioural changes and the development of new organisational identities that are aligned with digital workflows. In team-based project environments, success depends on team members building mutual understanding

and trust, ensuring standardised approaches to project documentation and consistently adhering to pre-agreed methodologies [1]. If these human elements are inadequately addressed, even the most advanced technological solutions may fail to deliver the intended benefits, resulting in compromised risk management, incomplete project information and missed delivery deadlines. This mismatch between technological capability and practical implementation is a critical challenge that needs urgent attention from both researchers and practitioners.

The fundamental challenge in current research is that the focus in the past has been on technology development rather than examining the dynamics of real-world implementation. As Björk [2] noted more than two decades ago, construction researchers have traditionally focused on developing innovative tools that would change industry practices rather than conducting comprehensive studies of existing realities without external influences. This bias in research has led to a significant knowledge gap regarding the actual experiences and challenges faced by end-users who must work in digital construction environments. While extensive literature exists on the technical specifications and theoretical benefits of CDE and BIM technologies, there is a lack of research that explores the practical barriers that hinder effective information management during the construction phases.

Analysis of existing research shows consistent patterns of challenges related to communication breakdowns, insufficient trust building between team members and inconsistent application of standardised procedures in project documentation. Furthermore, evidence from different construction contexts shows that projects with well-established collaborative frameworks and standardised procedures consistently perform better than projects without such foundations, regardless of their technological sophistication. This empirical basis demonstrates the importance of user-related challenges as primary determinants of digital construction success, rather than secondary considerations.

The practical implications of inadequate information management are particularly evident in local construction

environments where project teams work under considerable time pressure, resource constraints and complex coordination requirements. In this environment, ineffective information management can lead to significant cost overruns, schedule delays, quality issues and safety risks that directly impact community infrastructure development and the public good. When construction professionals struggle with unfamiliar digital systems, unclear operational protocols or inadequate collaboration frameworks, the consequences go beyond individual projects and affect overall community development goals. By focusing specifically on the experiences and challenges of end-users, this research addresses practical issues that have a direct impact on the successful delivery of construction projects and their ultimate contribution to societal wellbeing.

The aim of this research is to develop a robust analytical model to identify, categorise and evaluate the potential barriers and challenges that end-users face in managing information during the construction phase of building projects. It addresses the critical research gap by shifting the focus from technology-centred perspectives to user-centred analysis of digital construction environments. To achieve this goal, the research applies a systematic four-stage methodology: firstly, conducting a comprehensive literature review to provide the theoretical basis for the criteria assessment model; secondly, validating the identified factors; thirdly, determining their interrelationships; and finally, developing evidence-based strategic recommendations to improve information management practices in digital built environments. This comprehensive approach ensures that the research findings will provide actionable insights for both practitioners seeking to optimise the implementation of CDE and researchers seeking to improve the understanding of human factors in digital construction contexts.

## 2 METHODOLOGY

The main objective of the research is to develop a model to assess potential barriers and challenges faced by end-users in managing information during the construction phase. To understand the CDE, it is necessary to consider not only the technology, but also and above all the human factor that will drive it.

The workflow presented in Fig. 1 outlines the main phases of the research process and provides a structured approach for conducting systematic investigations.

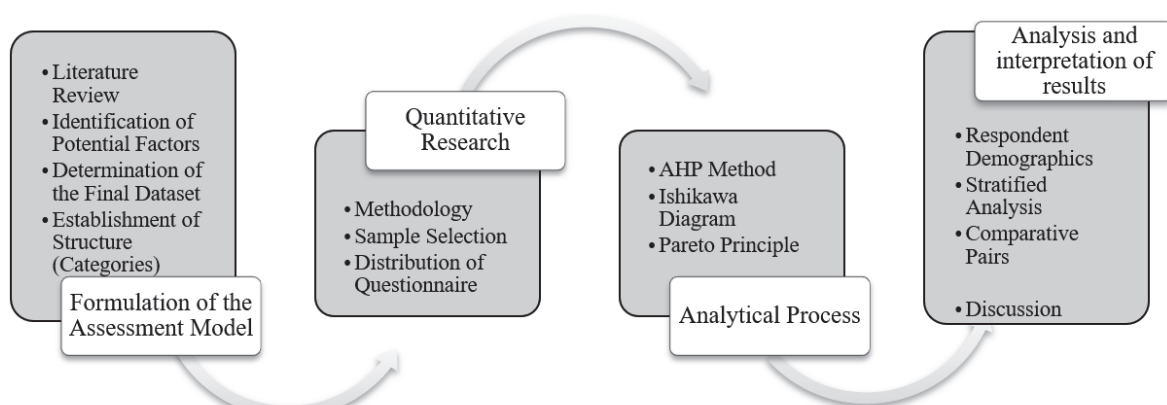


Figure 1 Research workflow for identifying and evaluating barriers to CDE adoption

### 2.1 Formulation of the Assessment Model

In the initial phase, an extensive literature review was conducted on the barriers and challenges to the adoption of CDE technology faced by people in the construction industry to develop a model to assess the criteria.

Next, we started to identify potential factors that could influence implementation. In compiling the factors, we focused not only on the most frequently mentioned, but sought to maximise diversity in the responses. In cases where the same factor appeared in multiple publications, we cited the most recent publication as the source. Based on the literature search through Google Scholar and Scopus, a total of 25 different factors were identified from studies in nine different countries (listed in Tab. 1). The identified factors were further corroborated by Jaskula et al. [3], whose study independently derived most of these same factors.

To efficiently determine and identify the nature of each identified obstacle and challenge, the process used the 5M method, according to which most problems and failures are concentrated in five categories: Manpower, Methods, Machines, Materials and Management [4]. The 5M method from Ishikawa is used to identify the main causes of product incompatibility and improvement actions [5].

When applying the 5M method, it should be noted that the classification of causes into individual categories can be flexible, as it depends very much on the problem and the characteristics of the area under investigation. Often there are causes that are difficult to categorize, such as environmental or financial causes.

### 2.2 Quantitative Research

Drawing on insights from our review and analysis of the existing literature, we designed and conducted a survey to support our analysis. Based on the results, we aimed to determine whether the increasing use of CDE technology in the construction sector has affected the construction companies where the selected candidates were employed.

We opted for an online survey to obtain this information. This is the easiest and quickest way to gather information without unduly burdening highly qualified employees [6]. It was important that the questionnaire was as comprehensive as possible and at the same time as short as possible to minimise the time required to complete it.

**Table 1** Identified challenges and obstacles in the implementation of CDE

#	Factor	Year	Source
1	Lack of appropriate end-user skills in managing data on CDE platforms created using advanced BIM tools.	2019	[7]
2	Low level of awareness of the benefits of using BIM/CDE technology.	2024	[8]
3	Lack of CDE/BIM technology experts.	2019	[9]
4	Businesses' reluctance to change and adopt new technologies.	2020	[10]
5	Entrepreneurs' fear of high-risk investment in BIM/CDE technology.	2021	[11]
6	Lack of financial support for businesses.	2019	[12]
7	There is no universal CDE platform available on the market that covers all the features needed to work efficiently.	2019	[12]
8	Despite the CDE technology, there are still too many other means of communication (e-mail, calls ...).	2018	[13]
9	Some collaboration tools used in industry are not compatible with open BIM formats such as IFC and BCF.	2016	[14]
10	Software in a foreign language only.	2008	[15]
11	Privacy and security concerns about data shared on cloud-based CDE platforms.	2017	[16]
12	Lack of standard contractual document that could help to build consensus on risk allocation and resolve potential disputes in the event of non-compliance with agreed arrangements.	2013	[17]
13	Participants are not contractually bound to use the Platform and shall not be liable for damages.	2021	[18]
14	Lack of culture, shared vision, and loyalty among company employees.	2015	[19]
15	Software is not user-friendly.	2017	[20]
16	High software rental costs.	2019	[21]
17	High staff training costs.	2019	[21]
18	Current lack of quantified (measured) evidence of the real cost benefits of using CDE/BIM technologies.	2019	[21]
19	Low cost of paper-based construction documentation.	2019	[21]
20	Insufficient management commitment to the implementation of new technologies.	2019	[21]
21	Outdated infrastructure in companies (computer, hardware).	2019	[21]
22	Lack of clear guidelines and standards for creating a collaborative BIM environment.	2020	[22]
23	There are no legal provisions to support the use of CDE, as is already the case in some countries.	2020	[23]
24	Lack of demand from clients or contractors to use CDE/BIM technologies on projects.	2024	[24]
25	The use of new technologies requires radical changes to current workflows and established practices.	2020	[25]

We decided to focus on the target group of candidates. The snowball method was used, one of the selective methods often used when sampling smaller populations of known individuals. A total of 50 candidates were invited to complete the questionnaire. They were selected according to certain criteria, i.e. the candidates were directly involved in the reference construction project or were known experts working in design or construction operations.

Each candidate received an email with an introduction presenting the context of the study, the objectives, the scope and the timeframe. At the end was a link to the survey with an explanation of the process, contact details in case additional questions arose, and a request to invite close colleagues in the field to participate. The questionnaire consisted of a series of demographic questions, a series of questions on the use of information and communication technologies or devices during the construction phase, a series of questions on users' experiences and expectations when using CDE platforms, and the most extensive series of questions aimed at identifying potential challenges and barriers to the wider adoption of CDE in practise.

This was followed by a systematic assessment of the identified factors using a quantitative decision-making method, i.e. an analytical hierarchical process (AHP).

### 2.3 Analytical Process

To analyse the relationships between the individual factors, we used the AHP method, which was developed in the 1970s by the American scientist Thomas L. Saaty and is still considered one of the most popular methods of multiparameter decision making, which converts a preference relationship into a utility function [26].

The method is based on the fact that although there are several criteria, the weighting of the individual criteria is not necessarily equal. The model component therefore does not cover this directly but uses a method of pairwise

comparison. This approach is also favoured by psychologists, who argue in their reports that it is easier and more accurate to express an opinion on only two alternatives than on all of them at once.

For the task at hand, we decided that a 3-point scale would be sufficient for the analysis: 1 - equivalence of the two categories, 2 - superiority of the first category over the second, 0.5 - inferiority of the first category over the second. The analyses were based on the average values of the ratings given by the individual respondents. This is a simplified approach, but one that has proved successful in the past [27, 28].

When analysing the results, we also paid attention to the consistency of the respondents' answers in the comparison matrices. According to Thomas L. Saaty, the consistency ratio, which measures the deviation from the consistency of the responses, must be less than or equal to 0.1.

The results were visualised using the cause-effect diagram, also known as the Ishikawa diagram or fishbone diagram. It is a visual tool used to identify and organise possible causes for a particular problem or effect [4].

The Pareto analysis was used to rank the identified factors in order of importance. This technique helps to focus on the problems that will have the greatest impact when they are solved. The Pareto principle is based on the 80/20 rule, which states that 80% of the negative effects are caused by 20% of the causes. The results of the analysis are presented in a Pareto chart, a statistical diagram that lists the causes or problems in descending order of frequency (bar chart) and cumulative impact (Lorenz curve).

The results of the pairwise comparison (Tab. 2) and factor weighting (Tab. 3) are presented alongside their visualisation in Figs. 3 and 4. These outputs directly reflect the application of the AHP method using the simplified 3-point scale, with values calculated from the average responses of all valid participants ( $n = 60$ ). The

stratification analysis (Fig. 3) further applies Pareto's 80/20 principle to highlight the most influential barriers.

### 3 RESULTS

The invitation to participate in the survey was sent directly to 50 candidates, asking them to forward it to their close colleagues for completion. A total of 70 questionnaires were completed, of which 60 were fully completed and 10 were partially completed and could not be used. Most questionnaires were completed on the day the initial invitation to participate was sent out and 11 days later when a friendly reminder email was sent.

#### 3.1 Demographic Picture

Most respondents belonged to the 31-40 age group (28), followed by the 41-50 age group (12), the 21-30 age group (11) and 51-60 age group (8). Only one person was over 60 years old and there was no representative younger than 21 years old.

Most of the respondents completed their last professional education or training in Slovenia, followed by India, UK, Spain, Slovakia, Croatia, Bosnia and Herzegovina. The most represented activity of the companies in which the respondents are employed is Engineering Design with 63%, the other activities are building construction (10%), inspection (5%), investments (3%), technical safety (2%), etc. Most of them are employed by small (10-49 employees) and medium-sized (50-249 employees) enterprises.

#### 3.2 The Use of ICT

The second part of the questionnaire contained questions on the use of information and communication technologies (ICT) and devices during the construction phase. In almost a third of cases (29%), most respondents communicate with other project participants by e-mail. A large proportion of communication (23%) takes place through face-to-face operational meetings on the construction site or at the company headquarters, and a slightly smaller proportion (15%) through group coordination meetings, which bring together a larger number of project participants. Remote meetings in the form of regular or video calls take place in 33% of cases, while those involved do not use text messages to communicate.

Digital formats are most commonly used by respondents to share various types of documentation, except for construction diaries, which are still predominantly kept in written form.

The question about where documentation is stored during the construction phase revealed that almost half of respondents (42%) store the necessary documentation on a network drive or a company server, a surprisingly high proportion of respondents (25%) still use local hard drives or optical media and USB sticks, 3% of respondents store documentation on email, 24% of respondents have opted to switch to cloud services, but only 6% in the form of a CDE platform.

When asked how often respondents access digital documents when they are on site, the same proportion

(17%) of respondents answered that they access documents both frequently and rarely. When using digital technologies to access documentation they most frequently use their mobile phones (40%), slightly less frequently their laptops (31%), tablets (17%) and desktop computers (12%).

It is surprising that 60% of respondents who visit construction sites still do not use digital devices in their work.

#### 3.3 Common Data Environment

In the third part of the survey, we asked some questions about users' experiences and expectations when using CDE. The answers show that the vast majority of respondents (77%) had heard the term CDE before the survey and only about half of them (53%) had a good idea of what CDE is.

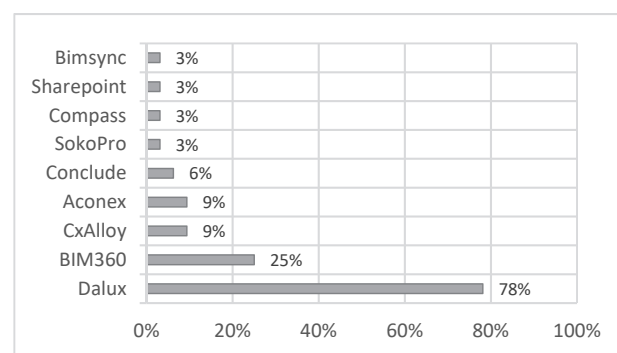


Figure 2 CDE solutions familiar to users. Multiple responses were allowed; therefore, percentages exceed 100%

The results show that 53% of respondents have used a CDE platform in the past. Most of them during their work in the construction phase (59%), slightly less in the planning and design phase (25%) or the management and maintenance phase (11%) and least in the takeover phase (5%).

We also wanted to know which the CDE solutions that users are familiar with are. Some users use multiple platforms. As can be seen in Fig. 2, the Dalux platform was the most used by respondents, who used CDE platforms, at 78%, BIM360 from Autodesk was the second most used tool (25%), followed by Aconex and CXAlloy at 9% and Conclude CDE from Thinkproject at 6%. The platforms least used by respondents (3%) were SokoPro, Bimsync, Sharepoint and Compass.

#### 3.4 Barriers and Challenges to CDE Implementation

The fourth and most comprehensive set of questions aimed to identify potential challenges and barriers to a wider implementation of CDE in practise. To facilitate understanding of the nature of their content and thus enable a more reliable response from respondents when completing the questionnaire, the factors collected from the literature review were categorised into five main categories using the 5M method described earlier:

- **Manpower.** The factors in this category mainly describe the attitude of employees towards new technologies and the nature of their work. Barriers limiting the adoption of CDE technology include

employee habits, unwillingness and fear of change, lack of desire for increased competence and very low awareness of the benefits of the technology at all stages of the project.

- **Methods.** In this category, the factors can be divided into two groups. The first group consists of obstacles related to developed methods and ways of working that are not standardized or the same for all active participants. The second group includes the lack of legal provisions that would support a faster introduction of CDE technologies, e.g., in public procurement.
- **Machines.** Barriers were classified in this category in relation to both the computer software and hardware available in the companies. Factors such as the lack of a universal solution on the market, outdated and inadequate equipment and the fact that user interfaces are not always available in the native language, which can cause problems for older users, were highlighted.
- **Materials.** The reasons that fall into this category relate to excessive software costs and staff training. In addition, no co-financing or subsidies are provided for the introduction of CDE technology to further motivate companies to implement it.
- **Management.** The last category included factors related to the organisational structures of private companies and public authorities, such as: poor corporate governance, lack of management commitment to the introduction of new technologies, unwillingness to cooperate better and reward employees appropriately, insufficient number of experts in the market, etc.

The first step in investigating the causal relationships between the factors was to identify and prioritise the individual factors. The analysis was carried out by comparing them in pairs, whereby the relative weighting of the main categories was first determined. Tab. 2 shows that the respondents attached the greatest importance to the categories *manpower* (26%) and *management* (26%), followed by *methods* (22%) and *materials* (18%) with a slightly lower share and *machines* (8%) with by far the lowest share.

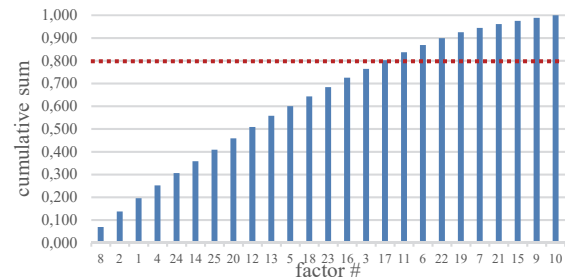
The next step in the analysis was to weight the importance of the individual factors. The relative weights of the factors determined using the AHP method were multiplied by the relative weights of the categories into which they were grouped to obtain the final absolute values.

**Table 2** Significance weights for the main categories. Results are calculated from valid responses (n = 60)

	Manpower	Materials	Methods	Management	Machines	Relative Weight
Manpower	1	1.45	1.21	0.93	3.62	0.26
Materials	0.69	1	0.75	0.73	2.37	0.18
Methods	0.83	1.33	1	0.82	3.08	0.22
Management	1.07	1.38	1.22	1	3.29	0.26
Machines	0.26	0.43	0.31	0.34	1	0.08

Based on the calculated values of the absolute weights of the individual factors, we have grouped them in

descending order in Tab. 3. It can be seen that the biggest challenge in the successful implementation of CDE is the simultaneous use of multiple means of communication, which in turn causes problems with the availability, transparency and reliability of information. At the same time, the construction industry faces the challenge that the benefits of utilising a CDE is not sufficiently known and understood. Another dilemma is the lack of end-user skills in using new software or the unwillingness of companies themselves to change established work processes and tools. Rounding out the top five factors for the lack of adoption of CDE is the fact that clients or contractors are generally not interested in using CDE platforms for their own projects.



**Figure 3** Results of stratification analysis using Pareto's 80/20 rule. Based on AHP analysis of survey responses

The addition of a cumulative total column in Tab. 3, using a stratification analysis based on the Pareto rule of 80:20, allowed us to identify the key areas and groups of factors where preventative action should be taken.

The results of the stratification analysis are also presented in the form of a diagram with a separating reference line illustrating the 80:20 rule. Figure 3 shows that among the 25 factors for the lack of implementation of CDE technology, the first 15 play a dominant role with a share of around 76.4%, while the remaining 10 factors account for around 23.6%.

Within the cumulative total of 80%, all 5 causes in the management category were covered, 4 each in the manpower and methods categories, and only 2 factors in the materials category. All factors in the machines category were excluded from the range of priority barriers, mainly due to the low relative importance of the category itself. The main reason for this is seen to be the wide choice of software on the market and the commitment of developers to upgrades, consistently considering feedback from their end-users.

The biggest challenge in the successful implementation of CDE has proven to be the simultaneous use of multiple means of communication, which leads to problems with the availability, transparency and reliability of information.

At the same time, the construction industry faces the challenge of low awareness and understanding of the benefits of utilising the CDE. Another dilemma is the lack of end-user skills in using new software or the unwillingness of companies to change established work processes and tools. Completing the top five factors for under-implementation of CDE is the fact that there is no general interest among clients or contractors in using CDE platforms for their own projects. This can be linked to several related factors which account for 80% of the total,

such as a lack of culture and shared vision among employees, organisations' fear of the risk of investing in new technologies and a lack of quantifiable evidence of the actual benefits of using CDE platforms in terms of cost savings.

For the in-depth analysis, additional comparison pairs were formed in which the respondents were divided into groups according to their position or profession (designers and others), their management position (management and others) and their age (under 40 and others).

**Table 3** Significance weights for the factors grouped into main categories, sorted by absolute weight. Based on AHP analysis of survey responses (n = 60). The cumulative sum column shows stratification according to Pareto's 80/20 principle

Factor #	Category	Factor	Absolute Weight	Cumulative Sum
8	Management	Despite the CDE, there are still too many other means of communication.	0.069	0.069
2	Manpower	Low level of awareness of the benefits of using BIM/CDE.	0.068	0.137
1	Manpower	Lack of appropriate end-user skills in managing data on CDE platforms created using advanced BIM tools.	0.058	0.196
4	Manpower	Businesses' reluctance to change and adopt new technologies.	0.056	0.252
24	Methods	Lack of demand from clients or contractors to use CDE/BIM technologies on projects.	0.054	0.306
14	Management	Lack of culture, shared vision and loyalty among company employees.	0.052	0.358
25	Management	The use of new technologies requires radical changes to current workflows and established practices.	0.051	0.409
20	Management	Insufficient management commitment to the implementation of new technologies.	0.050	0.459
12	Methods	Lack of standard contractual document that could help to build consensus on risk allocation and resolve potential disputes in the event of non-compliance with agreed arrangements.	0.050	0.509
13	Methods	Participants are not contractually bound to use the Platform and shall not be liable for damages.	0.049	0.558
5	Manpower	Entrepreneurs' fear of high-risk investment in BIM/CDE technology.	0.043	0.600
18	Materials	Current lack of quantified (measured) evidence of the real cost benefits of using CDE/BIM technologies.	0.042	0.643
23	Methods	There are no legal provisions to support the use of CDE, as is already the case in some foreign countries for public projects in BIM.	0.041	0.684
16	Materials	High software rental costs.	0.041	0.725
3	Management	Lack of CDE/BIM technology experts.	0.039	0.764
17	Materials	High staff training costs.	0.038	0.802
11	Manpower	Privacy and security concerns about data shared on cloud-based CDE platforms.	0.035	0.837
6	Materials	Lack of financial support for businesses (subsidies, etc.).	0.032	0.869
22	Methods	Lack of clear guidelines and standards for creating a collaborative BIM environment.	0.030	0.899
19	Materials	Low cost of paper-based construction documentation.	0.026	0.925
7	Machines	There is no universal CDE platform available on the market that covers all the features needed to work efficiently.	0.019	0.944
21	Machines	Outdated infrastructure in companies (computer, hardware).	0.017	0.961
15	Machines	Software is not user-friendly.	0.014	0.975
9	Machines	Some collaboration tools used in industry are not compatible with open BIM formats such as IFC and BCF.	0.013	0.988
10	Machines	Software in a foreign language only.	0.012	1.000



**Figure 4** Comparative pairs: importance of main categories of factors

major anomalies in the responses when categorising individual factors and their groups according to importance if the respondents were not considered as a whole. It turned out that all respondents thought very consistently and rated both the importance of the categories and the individual factors within these categories with minimal deviations.

Fig. 4 shows an example of respondents' answers when rating the importance of the main categories of factors. The graph shows that people who are not in leadership positions in their organisations, are younger than 40 and are not working as designers place slightly more importance on management, while older designers in leadership positions in organisations place the most importance on employee skills and awareness. When we look at the overall opinion of the respondents, both main categories are rated as completely equal.

#### 4 DISCUSSION

Work processes in the AEC industry are moving towards digitalisation. By providing a comprehensive

system to capture and analyse data during the construction project, CDE enables companies to gain much better insight into their workflows, leading to improved decision-making capabilities on current or future projects. In addition, advanced communication tools enable an open dialogue between all parties involved in the process so that any issues that arise can be resolved more quickly.

In the context of a construction project, a shared data environment provides a “single source of truth” by offering all project stakeholders a single and definitive location for project information in a standardised and structured format. It encourages members of the different project teams to collaborate and share information in a standardised way, rather than using email and other document sharing systems. If the systems of the different software suites are not integrated and do not have a central point of contact, project information becomes unreliable, opinions are given more weight than facts and implementation details become unclear, which can lead to cost overruns and construction delays.

It is widely acknowledged that the acceptance of new technologies in the construction industry is still relatively low. For some, digital transformation still feels like a giant leap into the unknown that could turn established ways of working upside down. When it comes to improving work processes with CDE platforms, one of the main reasons is a lack of adequate knowledge and awareness of the benefits that such technology brings. To remedy this, it is therefore essential to establish communication with the interested public and share as much as possible examples of best practise highlight risk opportunities and identify coping mechanisms so that potential new users are better able to manage the otherwise challenging and time-consuming implementation process.

that despite technological advances, fundamental organisational and human factors remain critical to success. This continuity of identified barriers suggests that the construction industry faces recurring challenges in technology integration, particularly in the transition from traditional practises to digital environments for collaboration. The persistence of these barriers in different technological contexts highlights the need for systemic approaches that consider not only technical capabilities, but also organisational culture, stakeholder engagement and user-centred design principles when implementing digital solutions.

**5 LIMITATIONS**

This study has several limitations that should be considered when interpreting the results. Firstly, the study is regionally limited and focuses primarily on a specific geographical area, which may limit the generalisability of the results to other construction markets with different legal, cultural or economic circumstances. Secondly, the sample size of respondents, although providing valuable insights, is relatively small and may not fully represent the diverse range of stakeholders involved in the implementation of CDE across the construction industry.

Despite these limitations, the study has notable strengths that add to its credibility and significance. The consistency of our findings with previous research on barriers to ICT adoption in construction serves to validate our methodology and emphasises the robustness of our conclusions. Furthermore, the in-depth analysis conducted in this study provides a nuanced understanding of the human factors influencing CDE adoption, which is particularly important in the context of Construction 5.0 where the focus shifts back to the human. This study's emphasis on putting the human element back at the heart of digital transformation represents a crucial contribution to the field and underlines that technological success ultimately depends on considering user needs, communication patterns and business behaviour, rather than purely technical considerations.

**6 CONCLUSION**

This study identifies key factors that influence the successful implementation of CDE in construction practice. Applying the inverse Pareto principle (commonly known as the 80/20 rule), we suggest that focusing on a critical subset of challenges can produce the most desirable outcomes. In particular, our findings suggest that removing approximately 20% of the major barriers - namely (1) consolidating communication channels, (2) increasing awareness of the benefits of CDE, and (3) improving staff skills through targeted training - can lead to significant improvements in the adoption and utilisation of CDE.

While the Pareto principle serves as a useful heuristic for prioritising actions, it is important to recognise that the remaining 80% of factors may also be relevant depending on the context. Therefore, the three areas highlighted should be considered as fundamental steps towards a more comprehensive digital transformation in construction rather than exhaustive solutions.

From a theoretical standpoint, this study contributes to the growing body of knowledge on digital collaboration in

	2005 (Lazarević) [29]	2009 (Kline) [30]	2007 (IT barometer) [31]	2002 (Singapore) [32]	2000 (IT barometer) [33]	1998 (IT barometer) [33]
Faster access to information	1	1	1	3	2	1
Information sharing	2	6	3	-	4	6
Improved communication	3	3	7	-	3	4
Managing large amounts of data	4	4	8	-	5	7
Better quality of work	5	5	6	2	7	2
Speed of work	8	2	4	1	6	3

Figure 5 Benefits of ICT use in the AEC industry in order of priority, as reported in selected previous studies

The results of this study are closely aligned to results of previous studies that have identified barriers to the adoption of ICT in construction. Previous studies have consistently emphasised communication problems, lack of awareness and inadequate training as the main barriers to successful technology adoption in the industry (Fig. 5).

Our research confirms that these long-standing problems associated with ICT adoption persist, suggesting

construction by emphasising the central importance of effective communication in CDE. Our findings show that current CDE implementations are often insufficient to enable meaningful interaction between stakeholders. Therefore, future CDE designs should integrate robust communication tools or ensure seamless interoperability with existing platforms.

Furthermore, this study calls for a re-evaluation of the way information exchange is conceptualised in the context of collaboration. Information is not simply stored - it should inspire action. Consequently, effective communication must be embedded in the design and use of CDE that go beyond passive file storage and enable active user participation.

In terms of usability, our findings emphasise the need for CDE platforms that are intuitive and require minimal learning. Taking inspiration from the widely used social media interfaces could be a viable way forward. Furthermore, the problems of "lack of awareness" and "insufficient training" should not simply be attributed to individual shortcomings, but should be critically viewed as systemic challenges rooted in organisational culture and technological readiness.

In summary, this study provides both practical guidance for industry practitioners seeking to optimise their CDE strategies and conceptual insights for academics investigating digital collaboration in construction. Future studies could explore the socio-technical dynamics of CDE use, evaluate the effectiveness of communication-centred CDE designs, and investigate strategies to promote user adoption without placing undue responsibility on end-users.

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