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The promise of BIM? Searching for realized benefits in the Nordic architecture, engineering, construction, and operation industries

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ABSTRACT

Benefits of BIM are not being achieved as expected in the mainstream architecture, engineering, construction, and operation (AECO) industries. Here, we aim to contrast expected and realized BIM benefits in AECO companies and discuss explanations for why benefits proposed in literature have, or have not, been realized. A qualitative research approach is applied to collect and analyse interview data from 47 companies in Finland, Norway and Sweden. Findings show that realized benefits typically occur "within the current practice" of individual organizations' project-related work. In contrast, expected but not realized benefits are long-term, lifecycle oriented and challenge current business and practice. Our proposed explanations acknowledge that fully realizing the expected benefits of BIM suggested in the technology-driven research is restrained by the current sector state-of-practice and assumes a high degree of BIM maturity among all cooperating companies. Thus, we discuss how explanations relate to the fundamental change required to radically leverage the benefits of BIM, challenging both current ways of work and the ubiquitous assumption of clients as drivers for BIM implementation in the sector. Based on our research, we argue that client demand is insufficient to realize the promise of BIM. Suggested research implications include a need for greater supply-driven logic among suppliers of BIM expert services, and the integration of multi-disciplinary competencies within and beyond the traditional disciplines. The research demonstrates the gap between state-of-the-art BIM predicted in literature and mainstream industry's adoption and highlights the importance of extending BIM research to better account for socio-organizational and process aspects of benefits and adoption.

1. Introduction

Digitalization in society is ongoing and governmental measures have been applied in most developed countries to drive and support such developments. In the Nordic countries, one of the most frequently discussed opportunities relating to digitalization in construction is BIM (Building Information Models, Modelling or even Management). Since the turn of the century, BIM as a means for progress has gained ground among researchers, policy makers and construction practitioners. The general understanding of BIM includes seemingly endless ideas of benefits relating to building design and construction and building lifecycle management. Recent research and developments include applications of BIM for the development of green buildings (for example, see the review by Ref. [1] and identification of the potential benefits of integrating BIM and sustainability practices in construction projects (for example, see the findings of [2]. The importance typically accredited to demand-side actors in driving innovation is also often related to building

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clients and owners as important beneficiaries of BIM [3–5]. Yet, BIM is still not commonly used in the vast majority of house-building projects, and the benefits of BIM proposed and identified by researchers are not being achieved at the predicted rate. In fact, whereas the benefits of BIM have been connected to the management of frequently highlighted challenges and needed developments in the construction sector, the gap seems to grow between the state-of-the-art BIM solutions and related benefits predicted in the literature and the mainstream industry's adoption and realization of it in the real-world practice. The research presented in this paper is an attempt to understand better the reasons behind this gap by exploring potential explanations for current BIM usage in the AECO sector in the Nordic countries of Finland, Norway and Sweden. Current BIM literature includes investigations of the usage of BIM and related potential benefits and/or barriers to implementation within the AECO sector [6,7] and for specific actors therein, including designers [4], constructors [8] and facility managers [9,10]. However, few have studied which and to what extent expected benefits are actually being realized in daily practice, and why. The intention is, therefore, to complement the extensive body of BIM research that focusses on opportunities offered by BIM and their practical benefits from (often) specific task/role perspectives.

The research design departs from the view of construction as a loosely coupled system (Dubois and Gadde 2002). Frequent explanations for loose couplings proposed by researchers include fragmentation of a system's external and internal environment, but also unclear means-ends connections [11]. Considering the latter, it is acknowledged that though the benefits of BIM proposed for building projects have been identified from research (for example, see Ref. [12], their realization calls for better acknowledgement of matters extending beyond the technical dimensions, including socio-organizational and process aspects [13,14]. Specifically, little attention has been paid to how different project stakeholders or building process actors understand, assess, and make use of BIM as suggested by researchers and BIM advocates. Following this notion, the "state-of-the-art" is at constant risk of not properly recognizing significant preconditions for technical achievements and BIM developments to translate into BIM benefits and, indeed, the gap is growing between the "state-of-the-art" and the "state-of-practice". To further the understanding of the realization of BIM benefits in business and everyday practice, we suggest that more attention should be paid to the frequently described fragmentation in construction, fragmentation that affects the construction process, disciplines and expertise, and construction network actors. The research presented is, in response, based on current BIM usage and understanding of its benefits from both separate perspectives (company view) and combined perspectives (network view) of companies in architecture, engineering, construction and real estate, that is, AECO actors.

More specifically, the research aim was to contrast expected and realized benefits of BIM and, from this, discuss potential explanations for why certain benefits (proposed in literature) have, or have not, been realized. The primary contribution of the research is to provide a critical reflection on the promise of BIM beyond the technology-driven approach prevailing in previous research. In the discussion, particular attention is paid to the following matters: the realization of benefits of using BIM assuming certain levels of BIM maturity, the frequently stressed role of clients in furthering the use of BIM, and AECO companies' understanding and realization of BIM as a means to support building lifecycle management. To support the discussion, a theoretical frame of reference was developed in line with the aim and research design. Section 2.1 introduces and discusses the concept of BIM maturity, including the maturity model by Bew and Richards [15] with widespread use among industry stakeholders. Section 2.2 outlines potential and observed benefits of BIM identified from relevant review articles and industry reports with a global perspective on BIM adoption and implementation. Section 2.3 provides a compilation of barriers for individuals and organizations to use BIM and realize related benefits suggested in literature. The methodological approach was qualitative and based on interviews with AECO companies conducted and analysed as described in section 3. The findings of the interview study are outlined in section 4. Potential explanations for the current state of realization of BIM are explored and discussed in section 5 and concluded in section 6, together with implications for practice and future research.

2. Theoretical frame of reference

2.1. BIM maturity model

BIM usage and implementation is the subject of a long-standing debate. To understand the concept, including potential benefits and their realization in construction practice, scholars have introduced and discussed the concept of BIM maturity. The frequently referred to maturity model by Bew and Richards [15] consists of four levels. Level 0 involves traditional handling of information in drawings and documents, and levels 1 and 2 involve collaboration between stakeholders with varying degrees of 2D, 3D and object-based information management using partially standardized formats. Level 3 describes a fully integrated approach in common information models, where the information is structured according to international standards and handled from a lifecycle perspective. Some researchers and BIM advocates speak of this approach by referring to the integration in models as being 4D (3D with time), 5D (4D with costs), and 6D (5D with additional information specific to operation and maintenance). Charef et al. [16] highlight that the nomenclature of dimensions beyond the fifth dimension is unclear, leading to the risk of losing the benefits these dimensions can contribute. However, in this study, we acknowledge that this way of organizing information in dimensions has been criticised because it assumes geometry as the basis for all information and that each dimension 4 to 6 builds on one another.

The maturity model by Bew and Richards [15] was designed for the design, construction, and handover phases rather than for operation and maintenance in the facilities management process [17,18]. Though the model is well known and frequently referred to by researchers and industry practitioners, its use for describing, assessing, and understanding BIM maturity on an organizational level has been contested. Liang et al. [19] noted the model's shortcomings in acknowledging different levels, such as project, company and industry. Siebelink et al. [20] argued that it takes more for an organization to develop mature BIM than the technological and organizational criteria described in the model. Ahankoob et al. [21] stated that the model fails to generate clear boundaries and differences between its proposed maturity levels.

Levels 1 and 2 are relatively well described, being based on the technology, standards and working methods that exist today, while level 3 rather describes a vision of how BIM could be applied. Attrill and Mickovski [22] stated that level 3 will be difficult to implement in the near future, partly due to a lack of knowledge and software coordination. Nývlt and Novotný [23] believed that level 3 requires new contractual relationships between parties and other risk-sharing models. Shrahily et al. [24] stated that level 3 is more complex than the other levels and presupposes organizational, process, and legal changes. The creators of the maturity model have also recognized this insight. HM Government [25] divided level 3 into four sub-steps and differentiated between technical and commercial aspects. Moving to level 3 is consequently described in the literature as a bigger step than attaining levels 1 or 2. The model by Bew and Richards [15] was originally proposed as a part of a UK national roadmap to implement BIM in the industry and to increase BIM maturity among companies. However, in this study, the model's maturity levels are not considered as measurements of individual companies' maturity, but rather as a description of how companies and organizations can collaborate with BIM under different conditions and achieve different types of benefits.

The potential benefits of BIM described in the next section differ between levels. Levels 1 and 2 can produce benefits such as collision control, visualization, a basis for simulations and generating drawings. At level 3, benefits associated with considerably greater effects, such as analysing and comparing many different solutions, integrating information flows, and performing life cycle analysis, can be realized.

2.2. Potential and observed benefits of BIM

Numerous studies propose and discuss BIM benefits. However, fewer studies report on observed BIM use and related benefits in real-world practice. To support further industry assessment of BIM benefits from different stakeholder perspectives, Zhou et al. [12] reviewed prior case studies evaluating advantages of BIM in actual construction projects. Zhou et al. [12] identified 23 project-level BIM benefit indicators (see Table 1). They divided the benefit indicators into four types, of which operational type benefits (especially efficiency-related ones such as reduced project duration and cost) were the most mentioned in the literature, followed by managerial and organizational benefits. Strategic benefits were the least mentioned in the literature [12], yet business-related benefits such as offering new services, marketing new business to new clients, and maintaining repeat business with past clients were already highlighted as important benefits by BIM users in the AECO sector a decade ago [26,27]. In this regard, McGraw Hill Construction [26,27] noted that more engaged and mature BIM users seemed to experience more internal business benefits than those in the early stages of BIM engagement.

The review by Zhou et al. [12] noted benefits for various actors (contractors, design agencies and owners) and in various phases (planning, design, construction, and maintenance/operation) of construction projects. They found that the reviewed studies were exclusively focussed on either overall benefits for the entire project lifecycle, or specific benefits for the design and construction phases. Eadie et al. [7] concluded from a survey of UK BIM that most BIM projects were handed over in 2D format, with the most beneficial asset data for facility managers not being provided at the end of the construction phase. Nevertheless, their survey also indicated that clients followed by facilities managers had the most to benefit financially from BIM implementation. In addition, and consistent with the findings of Zhou et al. they found that BIM use was often limited to the design and pre-construction stages, with less usage in the construction stage and little usage in the operation and maintenance (O&M) stages. However, based on a survey of UK and US owners' perspectives on BIM, McGraw Hill Construction [28] found that owners' BIM involvement was expanding, that many owners who use BIM see real benefits on their projects, and that interest in post-construction uses is emerging. A review by Pärn et al. [10] focussing specifically on BIM applications in facilities management (FM) identified six commonly outlined potential benefits in literature: increased utility and speed for data retrieval, enhanced collaboration, improved embedded building data, visualization of assets, longer equipment asset life, and more effective space/move planning (spanning from BIM maturity level 1 to 3, see section 2.1). Such benefits can result in *(inter alia)* information being more easily value-added and (re)used in FM, resulting in better asset management and/or built asset proposals being more rigorously analysed across disciplines enabling improved and innovative solutions [10]. Similarly, the review by Gao and Pishdad-Bozorgi [9] highlighted BIM's potential in facilitating O&M by helping facility managers to acquire, store and process building information more efficiently, and perform analysis to inform decisions.

Zhou et al. [12] identified relatively few practical studies attempting to assess the benefit of BIM on sustainability. However, according to a review by Wong and Zhou [29] on "green BIM" studies, which considered the use of BIM to help achieve sustainability goals over the entire lifecycle of a building, researchers advocate the potential of BIM to support environmentally sustainable building development through integrated design information and collaboration (in line with BIM maturity level 3, see section 2.1). Common examples of this include the use of BIM for analysing design stage energy performance and estimating carbon emissions of construction projects. In an international Delphi survey by Olawumi and Chan [2], the participating academics and industry practitioners agreed on three key benefits of integrating BIM and sustainability practices in construction projects. These were the ability to enhance

Table 1
Project-level BIM benefit indicators identified by Ref. [12] from literature on BIM implementation in actual construction projects.

Type	Benefit indicators
Operational	Reduced cost, Quality improvement, Reduced project duration, Improved safety, Visualization, Sustainable, Productivity improvement, Reduced change orders, Fewer claims/litigation, Reduced errors and omissions, Reduced rework, Prefabrication
Strategic	Competitive advantage, Market new business, Customer satisfaction
Organizational	Coordination improvement, Enhanced learning of staff, Economization of labour
Managerial	Communication improvement, Accurate data output, Model archiving, Negative risk reduction, Improved decision-making

overall project quality and efficiency, simulation of building performance and energy usage, and better designed products and use of multi-design alternatives. Based on a review on applications of BIM for the development of green buildings (i.e. buildings that limit negative impacts on the natural environment throughout their lifecycle), Lu et al. [1] deconstructed the BIM green building nexus into three main aspects: BIM support in the different lifecycle phases of green buildings, BIM functions for analysing various sustainability aspects of green buildings (energy use, carbon emissions, solar and lighting analysis etc.), and BIM support for holistic green building assessment (e.g. LEED, BREEAM). Both Olawumi and Chan [2] and Lu et al. [1] pointed out that, despite the benefits presented in the literature, the industrial acceptance of green BIM is still low.

2.3. Barriers for using and implementing BIM

From the diverse literature on perceived barriers for individuals and AECO organizations to start using BIM, a compiled picture was developed that organize suggested barriers into four categories to highlight technical as well as social dimensions: 1) technical barriers, 2) financial risk (or lack of incentives), 3) knowledge and competence, and 4) organization, management and working methods. According to the research design, the barriers were also organized to distinguish separate perspectives (company view) and combined perspectives (network view). Table 2 shows barriers related to individual companies or organizations implementing BIM (here referred to as 'company/organization level barriers'). Table 3 shows barriers strongly affected by relationships to other project stake-

Table 2
Company/organization level barriers identified from literature.

Technical barriers	Financial risks (or lack of incentives)	Knowledge and competence	Organization, management and working methods
Technically complicated [a, b, l]	High investment cost in technology[a,c,e,f,g,h,j,l]	General lack of knowledge/competence in BIM[m,c,d,f,g,j,l]	Lack of leadership[b,g,h,i]
Functional shortcomings [c, d, e]	High cost in competence and implementation work[e,f,h,k,l]	Lack of expert competence – BIM use level[m,c,d,e,f,h,i,l]	Difficulty/unwillingness to change working methods[a,d,e,j,l]
Deficiencies in software [d, f, l]	Unclear profit/benefit[e,g,i,j]		Organization and roles[g,k]
	The combination: Investment – unclear profit/benefit[d,e,f,j,l]		Need for changed business models[d,j,k]

[a] [30].
[b] [6].
[c] [4].
[d] [31].
[e] [32].
[f] [33].
[g] [3].
[h] [34].
[i] [35].
[j] [8].
[k] [36].
[l] [37].
[m] Barriers that address both the company level and the network relational level.

Table 3
Network relational level barriers identified from literature.

Technical barriers	Financial risks (or lack of incentives)	Knowledge and competence	Organization, management and working methods
Lack of, or incomplete, standards [c, e, g, h, l]	Low incentives for actors downstream in the value chain[c]	General lack of knowledge/ competence in BIM[m,a,d,g,l]	Client requirements[c,d,e,g,j,l]
Lack of software's ability to handle standards (interoperability) [a, c, f, h, k, l]	Low incentives for actors upstream in the value chain[g,k]	Lack of expert competence – BIM use level[m,h,i]	Legal regulations[b,c,d,e,f,g,h,l]
Lack of information chains – other actors' access to software [c, k, l]			Project organization[c,d,e,f,g,h,l]
			Process/working methods[b,e,f,g,l]

[a] [30].
[b] [6].
[c] [4].
[d] [31].
[e] [32].
[f] [33].
[g] [3].
[h] [34].
[i] [35].
[j] [8].
[k] [36].
[l] [37].
[m] Barriers that address both the company level and the network relational level.

holders or lack of agreements on the sector level that obstruct the use of standardized working methods (here referred to as 'network relational level barriers').

It can be argued from Table 3 that several barriers stretch beyond single companies' control. Overcoming them would require network relational level engagements in legal issues, standards, common processes and working methods, as frequently stated in research (e.g. Refs. [38–40]. Other suggested ways of overcoming barriers beyond single companies' control include client demand, especially from large public clients that could create sufficient demand, and subsequent drive, in the market (e.g. Ref. [39]. The identified need for open common standards has given rise to major international initiatives, such as buildingSMART. Researchers have also noted different levels of BIM maturity as a barrier to BIM use and implementation. Elaborating on BIM maturity [41], described the importance of collaboration and agreements beyond single projects, where many key stakeholders develop a common maturity level. An unequal maturity among stakeholders implies risks of an adjustment to the lowest level of use and benefit. Even some of the barriers related to using BIM in a single company (Table 2) can be hard to overcome for a single company. For example, technical barriers such as implementing hardware and software that are perceived too complex should, rather, be addressed by the software developers. Another barrier is high investment cost, combined with lack of reliable cost-benefit analyses. Ensuring return on investment for single companies is also concerned with whether investments made and benefits realized are connected or decoupled in the value chain [42]. showed in a case study that BIM caused an increase in design cost but a total saving for the project. In a study of return on investment when using BIM [43], a contractor was paid extra by the client for using BIM, motivated by the fact that the client benefits from the resulting cost savings. The contractor's benefit was not included in their analysis.

3. Method

Data collected for the research presented here is used to explore BIM usage and benefits (expected and realized) in search of explanations for the current understanding and realization of benefits in the AECO sector in the Nordic countries of Finland, Norway, and Sweden. The data collection was carried out within a research project that focussed on increasing competence in building construction in the northern region of these three countries.

The data collection took place over three years, from 2017 to 2019, and was carried out with project partner universities in the three countries that have well-established relationships with companies and BIM practitioners in the AECO sector. The project partners' prior knowledge about AECO companies in each of the three countries guided the selection of participants in the study. We wanted the selected participants to cover different sector actors, company sizes and geographical locations, and to include companies that were only active locally in the region and companies that also had operations nationally/internationally. In total, interviews were carried out with 47 companies involved in architecture, engineering, construction, and operation (see Table 4). To allow for a critical examination of the results of the interviews with companies, we also carried out interviews with 24 different trade and employers' associations that were active in the sector in the northern region to obtain a clearer idea of the representativeness of the sampled companies based on the associations' total (national) membership base.

The interviews were structured using an interview protocol with specific pre-defined, open-ended questions. The interview questions covered the following topics: the company's understanding of BIM, perceived driving forces and opportunities for the use of BIM in the AECO sector and the company, the company's interest in, use and maturity of BIM (according to Bew and Richards' maturity model, see section 2.1), the staff's BIM-related education, and finally, perceived preconditions and obstacles to increasing the use of BIM in the company. The interview protocol (available upon request from the corresponding author) was developed by two of the authors, piloted and revised in two phases. First, representatives of the project partners in the three countries reviewed the questions for clarity and content. Second, the interview protocol was pre-tested in interviews with four interviewees. Consequently, the interview protocol was slightly revised to improve clarity of the questions, and a set of more explicit questions regarding the use of BIM in supporting sustainable building practices was added.

The interviews were carried out by interviewers working for the project partner universities in the three countries and were held in the respondents' language (Finnish, Norwegian or Swedish). To ensure consistency in the application of the interview protocol and documentation, each interviewer received instructions for conducting the interviews from the authors who developed the protocol. The interviewers took notes during the interviews and some of the interviews were also audio recorded for later reference. Following the interview, the notes were summarized and transcribed by the interviewer. Transcriptions in Finnish and Norwegian were translated to Swedish prior to analysis. The translations were checked by native-speaking people whenever necessary to avoid misinterpretations.

The collected data were summarized and analysed qualitatively by two authors, who reviewed the transcripts separately and subsequently discussed their interpretations of the data based on the concepts and categorisations outlined in section 2. In this process, descriptive statements were extracted from the transcripts and, with the aid of the theoretical frame of reference in section 2, sorted and reviewed to identify: (1) current BIM use and maturity of the companies interviewed, (2) expected and realized benefits of BIM by the companies, and (3) barriers to using BIM and realizing benefits, as perceived by the companies. Since previous research by Ref. [37] identified a heterogeneity of the BIM adoption in the EU, differences in the data collected from the three countries were examined. However, as the findings in section 4 will show, no apparent differences were found. The analysis was cross-checked and validated by a third author with deep knowledge and experience of BIM and its practical use within the AECO industry in Nordic countries. For the most part, preliminary analyses were also discussed with the interviewers and the project partners' representatives to help ensure validity and reliability.

Table 4
Interviewed companies from the architecture (A), engineering (E), construction (C), and operation (O) sector. Swedish, Norwegian, and Finnish companies are denoted with subscripted letters (S/N/F). Different offices or business areas of the same company are denoted with x and y. *Note: Size of companies was determined according to EU norms: small (S), <50 employees and ≤ EUR 10 million turnover; medium (M), <250 employees and ≤ EUR 50 million turnover; and large (L), all which exceed medium-sized criteria.*

Company	Size	Market	Company	Size	Market
ARCHITECTURE			CONSTRUCTION		
A_S1 [a]	S	National	C_S1	M	Local
A_S2 [a]	S	National	C_S2	M	Local
A_S3 [b]	M	National	C_S3	M	Local
A_S4 [a]	S	National	C_S4	L	National
A_S5 [a]	S	National	C_S5[e]	L	National
A_S6	L	International	C_S6a and C_S6b[f]	L	National
A_N1	S	Local	C_S7	M	Local
A_N2 [a]	S	National	C_S8	M	Local
A_F1 [a]	M	National	C_S9	M	Local
A_F2	M	National	C_S10	L	International
ENGINEERING			C_N1	S	Local
E_S1x and E_S1y [c]	L	National	C_N2[a]	M	National
E_S2	S	National	C_N3	M	Local
E_S3	M	National	C_N4	S	Local
E_N1 [d]	L	National	C_N5	M	Local
E_N2 [d]	L	National	C_F1	L	National
E_N3	S	Local	C_F2[e]	M	National
E_N4	L	National	C_F3	L	National
E_N5 [b]	L	International	C_F4[e]	M	National
E_N6	S	Local	C_F5	L	International
E_F1 [b]	L	National	REAL ESTATE		
			O_S1	L	National
			O_S2	L	Local
			O_S3	M	Local
			O_S4	L	Local
			O_S5	L	National
			O_F1	L	National
			O_F2	L	Local

[a] Companies providing nationwide consulting or construction services, but primarily operating locally.
[b] National companies belonging to the same large international group.
[c] Two different business areas belonging to the same company.
[d] National companies belonging to large international corporate groups.
[e] Companies belonging to large national corporate groups.
[f] Two different local offices belonging to the same company.

4. Findings

Findings are outlined in three sections (4.1–4.3) representing the three subsequent steps of analysis described in section 3.

4.1. Current BIM use and maturity

An overview of the BIM maturity levels identified in the interviewed companies is presented in Fig. 1. The maturity levels (0–3) refer to Bew and Richards' model (see section 2.1). The overview shows differences between sectors regarding the maturity level, both when addressing BIM maturity from the perspectives of competencies within the organizations and the BIM level of projects they are involved in. The architecture (A) and engineering (E) companies, which operated at similar BIM maturity levels since they work in the same process of building design, seemed to operate mainly at maturity levels 1 and 2. All but one A company claim to operate mainly at level 2. Of the E companies, three out of ten stated they worked primarily at level 2. For the construction (C) companies, there is a greater spread of maturity levels. However, overall, the interview results suggest that construction companies with both in-house design and production functions operated at higher levels of maturity (typically levels 1 and 2) than companies who did not carry out design activities (typically level 0). The real estate (O) companies mostly operated at maturity levels 0 and 1. This pattern of maturity levels among companies appears similar for the three countries. It should be noted that the interview study with companies provides a limited description of the pattern of maturity levels in the AECO sector. However, interviews with trade organizations confirmed the extent of operating maturity levels regarding BIM use among their members.

4.1.1. The non-users

C companies that stated that they typically operated at level 0 seemed to associate BIM use mainly with designers and design phase work. Some companies stated that, though not using BIM themselves, they had begun to demand collision controls from designers when, for example, "*we have turnkey contracts and must put together all installations*" *[C_S3]*. Others did not seem to see how they, for their work in the production phase of buildings, could benefit from using BIM: "*We have no use for BIM. When we need to quantify [the*

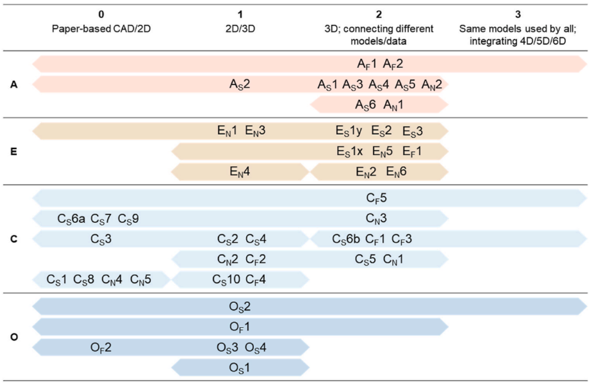

Fig. 1. Identified BIM maturity levels (0–3) of interviewed companies from the architecture (A), engineering (E), construction (C) and operation (O) sectors in northern Sweden (S), Norway (N), and Finland (F). The maturity levels are set according to Bew and Richards' model (as introduced in section 2.1). The name of each company corresponds with the maturity level that the company say they operate the most at. Note that the maturity level of OS5 could not be discerned from the interview and was therefore not included in figure. A colour print is recommended for better understanding this figure. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

material use], it is done from dimensional drawings" [C_S1]. Similarly, O companies typically concluded that they did not work with BIM themselves because they did not see any particular benefit, and that its use was mainly associated with building design. Even so, all but one O company claimed to operate mostly at BIM maturity level 1. However, O companies' internal work seems in line with level 0 of Bew and Richards' maturity model (see section 2.1). Some O companies stated that they require information to be delivered to them digitally and others stated that they could open, for example, CAD files and save them "*as PDFs and DWGs to be able to use them again when we rebuild" [O_S4].* To increase their BIM use and maturity level, one O company concluded that the benefits must become clearer, whilst another saw that the use and demand by project partners were an important driving force:

> "Most of the company (apart from the construction side) is not interested in BIM … We need to see benefits of using BIM [before our use can increase]." [O_F2]

> "We do not model anything ourselves. The role remains the client … If information models begin to be required by other project partners, the use will, of course, increase." [O_F1]

4.1.2. Differences in maturity levels within companies

As indicated in Fig. 1, large differences in maturity levels can also be present within companies: 20 of 47 interviewed companies stated that their work spanned across at least three different levels. Among them, companies that mainly operated at levels 0 and 1 seemed to associate these differences to *(inter alia)* different competencies among employees. For example, one C company operating mainly at level 0 described having *"only one person who runs BIM" [C_N4].* An E company working primarily at level 1 noted *"a segregation between those who master and those who do not master the digital tools that depends on both age and interest" [E_N1]* and saw differences between different offices at different locations, where offices "*in larger cities draw more themselves" [E_N1].* Others concluded that the maturity level depends on the project size. One C company operating mainly at level 0 explained that they commonly used *"paper-based information exchange in small projects and possible visualization in 3D in larger projects" [C_S7]* and an E company working mainly at level 1 described that the use of BIM in smaller projects "*is often a question of finances and whether the client requires it" [E_N1].* Even in companies that stated that they operated at a relatively high maturity level (up to level 2), some of the work and employee experience, particularly in the production phase, remained at a low maturity level:

> "[We] still work mostly with 2D drawings, however when [we] work with VDC, it is coordinated 4D in Revit where all designers link their models together into a main model." [C_S6a]

> "We use it in all phases of the construction process, but it is still a bit lacking on the construction site." [C_N3]

Regarding differences in maturity levels within companies, it is interesting to note that O companies essentially have two roles: client in projects and facilities manager. In their role as clients, O companies stated that other actors, primarily designers, greatly benefit from using BIM and that this use can also benefit the project although the company itself is not actively involved in using BIM. Some individual O companies also reflected on opportunities to use BIM to manage and coordinate the project. However, in their role as facilities managers, O companies commonly stated that they currently saw no significant use for BIM, that opportunities might exist, but that they needed help from suppliers (consultants and contractors) to see and realize the benefits in operation and maintenance (O&M) phases. For example, one O company described how it was, at that time, not the BIM models created in early project phases but, instead, construction documents and 2D drawings retrieved from such models that were digitally archived and later used to support O&M processes. They further described that they foresaw an increase in their use of BIM during O&M phases but, as argued by one O company:

"However, to achieve this, the other actors must sell the concept of BIM more specifically to us as a [real estate] company." [O_S2]

E companies claiming mainly to operate at maturity level 1 highlighted that benefits such as the ability "*to go into the model [to retrieve information]" [E_N4]* encouraged their BIM use. Among the companies stating that they primarily worked at maturity level 1, some also seemed to be approaching level 2 when *(inter alia)* they internally transferred information from design to process planning: "*We retrieve information from the 3D model and export it to our purchasing department for quantifying [the material use]" [C_S4]*. Another example is an A company who stated that a large part of their BIM work was finding "*a common way of working with other consultants" [A_S2]*. In this context, they referred to collision controls as *"the most requested BIM work" [A_S2]* and went on to explain that they could develop the model further by adding more data if their customers (contractors) wanted them to. One E company that stated that they primarily operated at level 1 also reflected on a BIM-supported transfer of information from designers to workers on site that was more in line with level 2:

"Fitters and technical personnel see solutions in viewers, BIM kiosks and Solibri … When we work with BIM, we always work based on the architect's model. This [architect] model must exist. Otherwise, there will be no modelling from us. In addition, the work in the model must be able to be done quickly." [E_N3]

4.1.3. Use for the benefit of who?

Most companies operating mainly at level 2 are quite a way from the fully integrated approach envisioned of level 3. Some A companies seem to use and develop their BIM practice mainly for their own benefit and, to a lesser extent, for collaboration with other actors:

"An important obstacle is that other disciplines do not always use it, and coordination between disciplines becomes more difficult when someone only uses 2D." [A_N1]

"We work in our various programs, and then we export and merge the IFC files." [A_S1]

One A company explained that BIM-supported collaboration was less common in the early project phases but more common "*in projects that have progressed, where we collaborate more broadly with the help of BIM." [A_S4]*.

Furthermore, companies operating mainly at level 2 (as with companies operating at lower maturity levels) frequently highlighted how it was only customer or client demands that pushed them into using BIM even more, and at a higher level:

"If the industry is not interested in us delivering BIM to any greater extent, we will not do so … Then we are more interested in developing our internal methods." [A_S1]

"There must be a requirement from customers for us even to start using all the possibilities with BIM … It is important that customers are willing to pay for this way of working and that everyone sees the benefits of BIM." [A_S3]

"We work with BIM daily in all projects and would like to be at the forefront and involved in development. However, we do not use BIM fully as this is not something our clients request. We believe that the use of BIM must increase in the industry before it can increase within the company." [A_S5]

"Customers in the market are a major factor in increasing the use of BIM within our company." [C_S6b]

There also appears to exist both company size and private/public client differences that affect how often customers request the use of BIM. For example, one A company stated that larger companies were at the forefront of development while the smaller ones were falling behind. An E company argued that *"larger customers have much clearer requirements for the use of BIM, where above all requirements for 3D design for coordination are included in the tender" [E_S3]* and that they experience increased demands from both private and public clients "*where the public clients have greater demands on the use of BIM in the projects" [E_S3]*.

Furthermore, there seems to be a mismatch between what suppliers can (technically) do and what the customers ask for, which indicates that there are differences in maturity levels between suppliers (especially A and E companies) and customers (C and especially O companies). For example, some A companies stated that they internally operate at a relatively high BIM level (mostly 2), but still deliver CAD files and 2D drawings to their customers. One A company explained:

"What we produce/deliver to the customer is more in a maturity level 1, while the projects are carried out in maturity level 2 and could have been delivered in maturity level 2. On the other hand, the exchange of information takes place mainly by dwg files and 2D drawings." [A_S4]

One A company reflected on how demands from customers are manifested, and an E company elaborated on what governs the customer's demand for the use of BIM:

"It is often the contract form that determines the possibility of using BIM. An architect is often the first to use BIM, while an engineer uses it if required. Spending time on it in the short term is not considered profitable, and you rather use what you know works." [A_N2]

"The customer's understanding of the benefits of BIM is crucial for us to increase our BIM use." [E_F1]

4.1.4. *Little evidence of fully integrated BIM*

A few respondents stated that their organization operated at levels which included elements of level 3 BIM. Among those were two large C companies. One highlighted that they *"want to be a forerunner" [C_F5]* by pushing projects and employees toward 4/5/6D modelling and issuing instructions to external actors such as designers and structural engineers. The other also mentioned that 4D and 5D modelling was used in several projects but that the customer's drive was important and concluded that *"it is not certain that we want to strive to achieve maturity level 3 fully, the part of the definition that states that all parties should work in the same model" [C_S6b]*. However, they noted an increased demand and interest from clients *(inter alia)* when it came to the potential usage of BIM to support facilities management:

> "They have shown an increased interest in using as much information as possible from the design phase all the way to the facility management phase of the construction process." [C_S6b]

Two more C companies stated that they operated at level 3. However, one of them said that they did so to a very low degree (only some development projects) and added that "*There is no life cycle information in any model" [C_F1]*. The other did not state anything that indicated that they operated at such a high BIM maturity level. Similarly, the two A companies who stated that they partly worked at level 3 seemed to feel ready to work at level 3, but there was nothing in the interview results to indicate that this has happened in practice.

4.2. *Expected, realized, and not realized benefits of BIM*

Expected and realized benefits of BIM identified from the interviews are summarized and presented according to the four types of benefits suggested by Ref. [12]: operational, strategic, organizational, and managerial. Corresponding to the identified BIM maturity levels in the companies (see section 4.1 and Fig. 1), respondents typically related "BIM" to "digital (3D) models" or even used the concepts interchangeably during interviews. The descriptions of realized benefits collected from interviews (see Tables 5–8 for an overview) generally confirm the expectations of BIM benefits mentioned by respondents, i.e., most of the expected BIM benefits have been realized by one or several of the interviewed companies (exceptions are expanded upon in section 4.2.5). This idea also includes expected favourable outcomes of BIM use that extended beyond the respondents' organization. For example, A companies described expected and/or realized benefits of BIM relating to construction (benefitting C companies).

4.2.1. *Realized operational benefits of BIM*

[12] found operational benefits to be the most mentioned in previous studies evaluating advantages of BIM in actual construction projects. Similarly, the accumulated interview data show that the operational benefits were the most expected, the most realized and the most definitively described of the four types of benefits defined by Zhou et al. (ibid.). Table 5 gives an overview of the identified realized operational BIM benefits.

The indicators "visualization", "productivity improvement" and "sustainable", as described by Ref. [12]; along with an additional indicator identified from interviews, labelled "simplifying/supporting core professional activities", were highlighted mainly by A and C companies but also by a few E and O companies. Looking at the indicators given by Zhou et al. for operational benefits, several companies also claimed to have realized benefits relating to quality, and errors and omissions. Regarding building lifecycle management, the benefits expressed by the respondents concerned either design or production and related to three subtypes of "sustainable": reduced/more efficient material usage, improved sustainability working practice and digital data supporting simulation.

Whereas the number of operational benefits realized by A, E and C companies exceeds the number of other benefit types being realized, this is not the case for O companies (compare overview in Table 5 with overviews in Tables 6–8). Apart from a few operational benefits related to the production and on-site management of projects, only two O companies concluded having realized operational benefits (one each) relating to facilities management (FM), including having exported the model (BIM) for operation and maintenance (O&M) systems. However, the expectations among O companies were that AEC companies should be able to benefit from their use of BIM by exploiting not only visualization and productivity improvement opportunities (e.g. by using BIM for quantity take-off), but also gaining time and cost benefits as well as supporting different types of simulations (beyond what is currently seen as common practice). Though these expectations among O companies are similar to those that A, E, and C companies describe, time and cost benefits were not typically presented as realized by the AEC companies this far. Moreover, though many of the operational benefits that were expected had been realized by one or several companies, some respondents noted that the fullest expected potential might still not have been reached, including e.g. benefits in terms of cost, time and project duration, efficiency, and different type benefits transforming into others. Similarly, whereas a few companies (representing A, E and O) claimed to have used the models to support energy simulations and verify energy efficiency, respondents from E companies concluded that, with more information, the results from such simulations and verifications could be further improved.

4.2.2. *Realized strategic benefits of BIM*

From the interview data, strategic benefits appear to be the least realized of the benefit types stated by Ref. [12]. Strategic benefits were also the least mentioned in the literature according to Zhou et al. (ibid). Table 6 presents an overview of the identified realized strategic BIM benefits.

A and E companies seem to have realized strategic benefits the most with no O companies and only one C company mentioning strategic benefits. It can also be noted that A and E companies that realized strategic benefits typically represent companies that operate at higher BIM maturity levels.

Table 5
Overview of realized operational BIM benefits identified from interviews with companies from the architecture (A), engineering (E), construction (C) and operation (O) sectors in northern Sweden (S), Norway (N), and Finland (F). Benefits are categorised according to the benefit indicators described by Ref. [12]; supplemented with additional indicators identified from the data.

Benefit indicator	A	E	C	O
Reduced cost	A_N1	E_N3, E_N5 *cost reduction on site [E_N5]*	C_N3	-
Quality improvement	A_S2, A_S3, A_S6 *better drawings and architectural quality [A_S3], support for self-checking [A_S3] and figuration [A_S6]*	E_N3	C_N4, C_F4	-
Reduced project duration	A_S4, A_N1, A_F1 *time reduction in production [A_N1]*	E_N3 *time reduction in production*	C_N3	-
Improved safety	-	-	-	-
Visualization	A_S1, A_S2, A_S3, A_S4, A_S5, A_S6, A_N1, A_F1, A_F2	E_N3, E_N4	C_S5, C_S6a, C_S7, C_S9, C_S10, C_N1 C_N4, C_N5	O_F2
Sustainable	A_S2, A_S3, A_N1, A_N2 *reduced use of paper [A_N1] and material waste [A_S3]; improved sustainability working practice [A_S3]; energy and indoor environment simulations [A_N2]*	E_S3, E_N1, E_N5 *better material efficiency [E_N1], reduced material usage [E_N5]; energy simulations [E_S3]*	C_N3 *more precise material quantities, better use of space*	O_S2 *energy simulations*
Productivity improvement	A_S1, A_S3, A_S4, A_N1, A_F1, A_F2 *faster/more efficient work by* e.g. *quantity take-off [A_N1, A_F2], drawing generation [A_S1, A_S4], reduced duplication of work [A_S3]*	E_S1x, E_S1y *faster/more efficient work by* e.g. *quantity take-off [E_S1x], drawing generation [E_S1y], combining BoM/3D-models and scheduling [E_S1x]*	C_S3, C_S4, C_S6a, C_N2, C_N3, C_F1, C_F5 *faster/more efficient work by* e.g. *quantity take-off [C_S4, C_S6a, C_N3, C_F1], drawing generation [C_N2]*	O_S1, O_S2, O_F2 *faster/more efficient work by* e.g. *quantity take-off, drawing generation [O_S2], digital handling of building documentation [O_S1]*
Reduced change orders	-	-	-	-
Fewer claims/ litigation	-	-	-	-
Reduced errors and omissions	A_S3, A_N1	E_S1x, E_N1, E_N3, E_N5 *in deliverables [E_N1], design [E_S1x] and production [E_N1, E_N3]*	C_S2, C_N3 *by earlier detection of misunderstandings [C_S2]*	-
Reduced rework	-	E_N1 *by earlier detection of errors*	-	-
Prefabrication	-	-	C_S4 *machine control in factory*	-
Additional indicators:				
- Simplifying/ supporting core professional activities	A_S2, A_S3, A_N1, A_F1, A_F2 *design [A_N1, A_F1], calculations [A_S3, A_F2]*	E_S1x, E_N1, E_N4, E_N6 *design [E_S1x], HVAC work [E_N1], construction management [E_N4]*	C_S7, C_S9, C_S10, C_N2, C_N3, C_F1, C_F2, C_F4, C_F5 *design [C_S7, C_S9, C_N3, C_F4, C_F5], calculations [C_N3], on-site production [C_F1, C_F2] and in factory [C_S10]*	O_S2, O_F1 *O&M by FM models*
- Digital deliverables/ drawings	-	E_S1y, E_N2, E_N5	C_N4	-

Table 6
Overview of realized strategic BIM benefits identified from interviews with companies from the architecture (A), engineering (E), construction (C) and operation (O) sectors in northern Sweden (S), Norway (N), and Finland (F). Benefits are categorised according to the benefit indicators described by Ref. [12]; supplemented with additional indicators identified from the data.

Benefit indicator	A	E	C	O
Competitive advantage	A_S4, A_S6, A_F1, A_F2 *by presenting opportunities for offering early stage analyses [A_S6] and BIM competence [A_F2] responding to client expectations [A_F1]*	E_S1x, E_N1, E_N2, E_N5, E_F1 *by reduced cost [E_N2, E_N5], supporting service offers [E_N1], responding to client requirements [E_F1]*	C_F5 *forefront indicator*	-
Market new business	A_F2 *BIM management services (CAVE), O&M applications for energy and indoor environment*	E_N2 *opportunities for centralization of O&M*	-	-
Customer satisfaction	-	-	-	-
Additional indicators:				
- Sector/industry level developments (BIM driven)	A_F1	-	-	-

Table 7
Overview of realized organizational BIM benefits identified from interviews with companies from the architecture (A), engineering (E), construction (C) and operation (O) sectors in northern Sweden (S), Norway (N), and Finland (F). Benefits are categorised according to the benefit indicators described by Ref. [12]; supplemented with additional indicators identified from the data.

Benefit indicator	A	E	C	O
Coordination improvement	A_S1, A_S2, A_S3, A_S4, A_S5, A_N1, A_N2, A_F1, A_F2 *stakeholder coordination [A_S3, A_N2, A_F2] and better, simpler project overview [A_S3]* by e.g. *collision control [A_S1, A_S2, A_S5, A_N1, A_N2, A_F1, A_F2], coordination models/one collective model [A_S1, A_N1, A_F1, A_F2], common way of work [A_S2]*	E_S1y, E_S2, E_S3, E_N1, E_N2, E_N3, E_N4, E_N6 *stakeholder coordination [E_S3, E_N6] and construction manager support [E_N4]* by e.g. *collision control [E_S1y, E_S2, E_N1, E_N3], coordination models/one collective model [E_S1y, E_S2, E_N1, E_N2]*	C_S3, C_S4, C_S6a, C_S7, C_S9, C_N2, C_N3, C_N4, C_F1, C_F5 *stakeholder coordination [C_N3, C_F5]* by e.g. *collision control [C_S3, C_S9, C_N4], coordination models/one collective model [C_S6a, C_N2, C_F1]*	-
Enhanced learning of staff	-	E_N5 *competence enhancement*	-	-
Economization of labour	-	-	-	-
Additional indicators:				
- A new way of working (digitalization driven)	-	-	C_S6b *integrating design and production*	-

Table 8
Overview of realized managerial BIM benefits identified from interviews with companies from the architecture (A), engineering (E), construction (C) and operation (O) sectors in northern Sweden (S), Norway (N), and Finland (F). Benefits are categorised according to the benefit indicators described by Ref. [12]; supplemented with additional indicators identified from the data.

Benefit indicator	A	E	C	O
Communication improvement	A_S1, A_S3, A_S6, A_N1, A_N2, A_F1, A_F2 *stakeholder understanding/ communication quality [A_N1, A_N2, A_F2], marketing and sales support [A_N1, A_F2]; digitally collect/convey/ maintain/retrieve information [A_S3, A_S6, A_N2, A_F1] and transfer rich, versatile data [A_S1, A_N2, A_F1]*	E_S3, E_N2, E_N3, E_N4, E_N5, E_N6 *stakeholder understanding/ communication quality [E_N2, E_N6], information coupling [E_S3]; digitally collect/convey/ maintain/retrieve information [E_S3, E_N2, E_N3, E_N4, E_N5]*	C_S2, C_S3, C_S4, C_S5, C_S10, C_N2, C_N3, C_F1, C_F2, C_F4, C_F5 *stakeholder understanding/ communication quality [C_S2, C_S3, C_S4, C_S5, C_N3, C_F5], marketing and sales support [C_S10, C_F1, C_F4], information exchange by coordination models [C_F1]; digitally retrieve information [C_N2, C_F2] and transfer rich, versatile data [C_F5]*	O_S3, O_S4, O_F1, O_F2 *marketing and sales support by visualization [O_F2], information exchange between AEC and O [O_S3]; digitally retrieve information for O&M [O_S4, O_F1] and energy calculation [O_F2]*
Accurate data output	-	-	C_S2, C_S3, C_N3, C_N4, C_F1 *more accurate/detailed information [C_S2, C_S3, C_N3, C_N4] for scheduling, time, cost estimations/control [C_N3, C_F1], 4/5D [C_F1]*	O_S2 *4/5D*
Model archiving	A_F1 *rich and precise documentation*	-	-	O_S1, O_S2, O_S4, O_F1 *2D-digital documentation [O_S1, O_S4], model-generated drawings [O_S2] and other building documentation [O_S1, O_F1]*
Negative risk reduction	-	-	-	-
Improved decision-making	-	E_N5 *model-supported project follow-up*	C_S4, C_N3, C_F1 *basis for purchasing, scheduling [C_S4, C_N3], planning, control, and follow-up [C_N3, C_F1]; support for project management [C_N3]* e.g. *onsite planning, control, follow-up [C_N3, C_F1] and timely delivery of material [C_S4]*	O_S2, O_F1 *basis for early design [O_S2]; support for cost/time planning [O_S2] and users' decision-making [O_F1]*
Additional indicators:				
- Digital information flows	-	-	C_S6b *supporting virtual design and production*	-

A and E companies described opportunities for maintaining or strengthening “competitive advantage” as being through reduced costs and a better response to expectations of leading clients by offering early stage analyses, BIM competence and supporting service offers. One A and one E company described benefits related to “market new business”. These benefits were opportunities for centralization of O&M, and how BIM applications for monitoring and controlling energy performance and indoor air quality were developed and used.

Overall, respondents related the realization of strategic benefits to a niche market or even a specific client/project. An additional benefit mentioned by one A company concerned how BIM drove sector/industry level developments. By developing their abilities and using BIM, some companies noted that they were better prepared for responding to client requirements regarding *(inter alia)* 3D structural design and design-related services for building maintenance, monitoring and support. However, though such benefits may be realized in technical terms, they are, according to respondents, not yet fully realized in business terms due to limited demand, and the general set of clients being unaware of their potential.

4.2.3. Realized organizational benefits of BIM

As shown in Table 7, realized organizational benefits were described by most A and E companies and about half of the C companies. The most frequent benefits relate to "coordination improvement", including coordination of stakeholders and work. Coordination benefits are, in turn, typically referred to as benefits resulting from the use of 3D visualization (operational benefit, see section 4.2.1), the use of coordination models and the possibility of carrying out pre-production collision controls. Visualization was described as supporting stakeholder coordination by helping actors achieve managerial benefits (see section 4.2.4) such as information exchange and a shared and mutual understanding of the building and the project (e.g. attaining a better project overview).

Whereas "coordination improvement" (supporting current project management practice) was explicitly described by many A, E and C companies, organizational benefits that relate to "enhanced learning by staff" and "economization of labour" were less frequently mentioned. Moreover, none of Zhou's organizational benefit indicators was mentioned in the interviews with O companies.

4.2.4. Realized managerial benefits of BIM

Table 8 shows that, for A, E, C and O companies, "communication improvement" was the most realized of the managerial benefit indicators described by Ref. [12]. "Communication improvement" was often described in terms of one, or both, of the following:

- Models being used for presenting purposes (using visualization), for example, supporting communication with users, clients and local planning authorities (thereby improving coordination), and helping assessment and "improved decision-making" (e.g. regarding early design, purchasing, planning and control as mentioned by E, C and O companies, see Table 8).
- Models being used for collecting, conveying, and maintaining information (from the outset and throughout the project), helping transfer information between actors and enabling easy access by being readily retrievable from the digital model.

Whereas O companies mainly related realized benefits to project management, benefits related to "model archiving" were highlighted by four O companies and "communication improvement" by digitally retrieving information for O&M by two O companies. C companies mainly mentioned realized benefits related to "accurate data output", including more accurate/detailed information for scheduling, time, and cost estimations/control. Additional benefits described by one C company concerned their use of BIM to achieve digital information flows (see Table 8) and "a new way of working" (organizational benefit, see Table 7). Similar to companies identifying connections between managerial and other types of benefits, the C company stressed that the realization of these benefits depended on and impacted other cooperating parties in construction projects.

4.2.5. Expected but not realized benefits of BIM

Though the collected descriptions of realized benefits generally confirm individual companies' expectations of BIM benefits, some benefits described by respondents do not seem to have been realized in any of the organizations addressed, see Table 9.

A frequently highlighted benefit of BIM is the replacement of paper drawings with digital models, for example, on-site access using tablets. However, (paper) drawing-free construction was not described by any of the respondents, either as realized by themselves, or as otherwise observed in practice.

Other frequently proposed benefits of BIM relate to later stages in the building lifecycle, including aspects of O&M and sustainability. The interview results indicate that, although many respondents have clear expectations, realized O&M benefits of BIM are rare. This is consistent with the findings of [7,12]. O&M benefits would, according to several A and E company respondents, be possible for them to support at present. However, few such offers are currently made due to a lack of client demands. Regarding benefits discussed by Refs. [9,10]; only two Finnish A companies and one Norwegian E company explicitly stated that they, in response to client demands, had developed BIM-based applications for supporting monitoring and control of energy and/or indoor environment performance. Still, the use of such BIM applications in combination with sensors (Table 9 [E_N1]) and IRL update of data (Table 9 [E_N3]) remains unclear. Finnish and Norwegian respondents related this type of business offer to demands from public clients.

Some energy performance-related benefits had been realized. In addition, s few respondents recognized the potential of BIM for supporting environmentally sustainable building development beyond energy performance calculations, simulations, monitoring, and control (this has been recognized previously by Ref. [29], see Table 9. Examples include using BIM to aid the performance and use of lifecycle analysis (LCA), lifecycle costing (LCC) and material documentation in the design phase. Though respondents noted that such benefits are possible, none described having realized them, either as an operational benefit to support better work efficiency or as a strategic benefit producing new business opportunities.

4.3. Barriers to using BIM and realizing benefits

Respondents' perceived barriers to using BIM were identified from the interviews and are summarized in Table 10. The identified barriers were categorised according to the structure shown in Table 2, with four main categories of barriers and two levels.

Table 10 shows some clusters with a high proportion of respondents indicating perceived barriers. Three of the four largest clusters are in the "Organization, management and working methods" category at the company and network levels. The fourth is in "Knowledge and competence", which also appears to present significant barriers. However, the technology itself seems less of a barrier for the respondents. Perceived barriers belonging to each category are described in more detail below.

Table 9
Overview of expected benefits of BIM use that none of the respondents described as realized.

Type	Operational	Strategic	Organizational	Managerial
Project lifecycle				
Production benefit	iPad used at building site for enabling streaming of BIM model [E_N2]			
Client benefit	Clients' procurement basis [A_S1]			
Building lifecycle				
Operation and maintenance (O&M) benefit	Use of sensors to create digital twin for energy performance monitoring and control [A_N1] BIM-supported follow-up of sustainability features [E_N4] Clients' use in O&M phase could be supported by information in models [A_N2, E_N2, E_N4] Use of sensors in models and visualizations for energy performance monitoring and control [E_N1] IRL updated data used for better energy performance monitoring [E_N3] Improved O&M [C_S6b, O_F2]	More information in model may enable the creation of checklists for O&M [C_N3]		IRL updated data used for better energy performance monitoring [E_N3] Model is continuously updated to keep track of changes [C_N2] Information availability, all information gathered in one place [C_S6b] Improved data retrieval for O&M [C_N4, O_S5], e.g. where cables are located [C_N4] All (project) information collected in one model to support sustainable building [C_F3]
Sustainability benefit	Support energy calculation and visualization in 3D [A_N1, A_N2] Support environmental analyses beyond energy considerations [A_S3, A_S6, C_S6b, C_S7, O_F1], e.g. LCA analyses [A_S3, C_S6b] and carbon footprint [O_F1] Automated material documentation and automated LCA/LCC [A_S1]	Software development for energy calculation and visualization in 3D [A_N1] Support environmental and lifecycle analyses beyond energy analyses [A_S3, C_F5], e.g. LCA and/or LCC analyses [A_S1, C_S6b] and carbon footprint [O_F1] Support environmental analysis based on different design choices [C_S10] Enable (better, proactive) response to environmental demands [C_S6b] Improved planning enabling long-term sustainable solutions [C_S6a]	Support information management across building lifecycle stages [A_S1, A_S5]	BIM-supported LCC and LCA analyses [O_S2] Lifecycle information included and contained in model [C_F1] Support quality and environmental management systems with information management [O_S5]

4.3.1. Technical barriers

Technical barriers seem to be of less importance than organizational and knowledge related barriers. For example, lack of, or incomplete, standards were only highlighted by a few respondents. The standards requested by a C and an A company were not formal standardization work but rather guidelines and manuals for applying those standards by the industry. The two respondents wanted national BIM manuals to unify the work in the sector and avoid company-specific solutions. Other technical barriers mentioned were the level of detail on information in the models, more automated functions, and some problems with computer speed when using larger models.

4.3.2. Financial risks

Few respondents mentioned the actual investment in hardware and software as a barrier, but rather the costs related to building knowledge about BIM in the organization. One of the A companies considered the most important prerequisite to be able to finance the education and training needed. Similarly, one O company described how the actual use of tools is linked to their costs.

In respect of risk and lack of incentives, the cost-benefit analysis, where the perceived benefit can be calculated related to the investment, was the most critical barrier/precondition for several actors. Several C companies highlighted the importance of being able to show the profit from an investment, and one E company described how the most important prerequisite was that BIM created increased competitiveness for the company.

At the network level, respondents mainly from A and E companies stated that the financial barriers were related to clients' understandings of BIM and its potential benefit (in terms of explicit value for clients). This included understanding how the client organization benefits from demanding BIM use to create such value, and the investments needed to realize them. For example, an A and an E company pointed out that clients must see the benefits of BIM and accept the associated costs. Another A company argued that, with traditional contracts, you were not paid for delivering models, and that other contractual arrangements, such as partnering, would be needed to allow for making "full use" of BIM throughout the construction process.

4.3.3. Knowledge and competence

From a breadth of actors, there were barriers perceived in terms of a general lack of knowledge in BIM in the company and a lack of skills and expertise to put technical opportunities into practical use. Respondents from each trade claimed that the most important precondition was a common understanding in the company of how BIM might support the business, and a common knowledge of BIM use.

Table 10
Respondents' perceived barriers to implementing BIM and realizing benefits.

Technical barriers	Financial risks (or lack of incentives)	Knowledge and competence	Organization, management and working methods
Company/organization level			
Technically complicated E_N3	High investment cost in technology E_N4, C_S4	General lack of knowledge/competence in BIM A_S3, A_N2, E_N1, E_N3, E_N4, E_N5, E_N6, E_F1, C_S2, C_S3, C_N5, C_F4, O_F1, O_F2	Lack of leadership A_F2, E_N4, E_F1, C_F2, C_F4, O_S2
Functional shortcomings E_N2, C_F2, C_S4, C_S7	High cost of competence and implementation work E_N4, C_F2, O_S2, O_S5	Lack of expert competence – BIM use level A_S4, A_N2, A_F1, E_N4, C_F1, C_F4, C_F5, O_S1	Difficulty/unwillingness to change working methods A_S3, A_F2, E_N1, E_N6, E_F1, C_S4, C_S6b, C_S9, C_S10, C_N1, C_F1, O_S2, O_F1, O_F2
Deficiencies in software C_N4, C_F5	Unclear profit/benefit A_S4, E_S2, E_N1, C_F1, O_S2, O_F2 High investment cost in relation to unclear return on investment E_N2, C_S5, C_S6a, C_N4, O_S3, O_S5		Organization and roles – Need for changed business models A_S1
Network relational level			
Lack of, or incomplete, standards A_S3, C_N3	Little incentive for actors downstream in the value chain A_S1, A_S3, A_N2, E_F1, C_S1, C_S6b, C_F1	General lack of knowledge/competence in BIM A_S3, A_S6, A_F2, E_N5, E_F1, C_S9, O_S2	Client requirements A_S2, A_S3, A_S4, A_S5, A_S6, A_N2, A_F2, E_S1x, E_S2, E_S3, E_N1, C_S2, C_S3, C_S6aC_S6b, C_S10, C_N2, C_N5
Lack of software's ability to handle standards (interoperability) C_S9, C_F3	Little incentive for actors upstream in the value chain-	Lack of expert competence – BIM use level C_N3	Legal regulations A_S3, A_N2, C_S9
Lack of information chains – other actors' access to software -			Project organization A_S2, A_S5, A_N1, A_N2, E_S3, E_N2, E_N3, C_S1, C_N1, C_N3, C_N4, C_F3, O_F1, O_F2 Process/working methods A_N1, A_F1, C_F3, C_F5

At the network level, several A and E companies claimed that the client's understanding and knowledge was an essential obstacle. However, one C company also pointed out a lack of knowledge by the designers, architects and engineers, who did not deliver models suitable to support the construction work.

4.3.4. Organization, management and working methods

As BIM is introduced, and to maximize gains from potential benefits, attitudes towards changing current ways of working were suggested as a barrier by several respondents. The respondents pointed out general resistance to changing habitual working methods by several actors: designers, construction workers, white-collar workers on site, and at real estate companies. Some described age structures as a reason, while others believed that personal characteristics and individual attitudes were of more significance.

Some respondents also pinpointed a lack of leadership at the company level as a barrier to realizing benefits of BIM. Several believed management needed more time and resources to develop and educate the staff.

From a network perspective, the client's requirements seemed to be important, as well as how projects were organized, which were also factors controlled by the client. The realization of expected strategic benefits of BIM use (referring to benefits presented in Tables 5–9) was frequently described as involving the recognition of value by other organizations, primarily by O companies and other potential clients (for an illustration see e.g. quotes by A_S3, A_S5, E_F1 and C_S6b in section 4.1). The need to enhance the level of what is generally demanded was highlighted by some respondents. For example, C_S6b argued that macro-level societal demands could drive companies towards using higher BIM maturity levels faster. Many respondents used similar words to express how increased demands and requirements from the client were needed to achieve a change towards greater BIM use. The motives stated were that the client was the party that coordinated all actors in the project and could benefit the most from the use of BIM in the end. Respondents gave several examples of when they depended on other actors' information or vice versa, and how the project organization needed to ensure that every actor received the correct information in the correct format.

5. Discussion: potential explanations for why some BIM benefits have been realized, and why some have not

From the collected interview findings, it appears that many of the BIM benefits highlighted in literature were not only expected by respondents but had, indeed, been tested in projects and realized by at least one or two companies. Similar to the findings by Ref. [7]; the most frequently realized BIM benefits relate closely to the construction process, to the design phase in particular (where the use of BIM by A and E companies could be understood in terms of a level 2 maturity, for the most part), but also the construction phase (where C companies seemed to exhibit more diverse levels of BIM maturity). Realized benefits also seem to be, typically, focussed on and/or originating from operational benefits that provide a solid and reasonably direct benefit to the user, supporting current practice in day-to-day work in projects. However, for the BIM benefits proposed in literature to yield more significant effects in industry, the findings indicate that they are much more difficult for companies to realize. First, expected but not realized sustainability and operation and maintenance phase benefits (i.e. building lifecycle-related benefits, see Table 9) seem to involve the leverage of multiple benefits, operational as well as organizational and managerial. Second, many stakeholders, clients in particular (c.f. [7], do not currently use BIM at any level (i.e. they operate at level 0 maturity) and the realization of benefits at the network level requires changes in current regulations and norms (including working methods, roles and responsibilities understood as “common practice” in Sweden, Finland and Norway).

Could the reason for why certain benefits suggested in literature have been realized, whereas others have not, be found in the very nature of the change required to move between different BIM maturity levels? In line with [41] work on BIM implementation maturity, findings from this study seem to suggest that some moves between levels in the often cited model by Bew and Richards [15] call for changes at company level, whereas others require a change in the network. Subsequently, challenges encountered by companies and projects are generically different, depending on what level-related benefits of BIM they are aiming to realize. This is illustrated in Fig. 2. Further elaborating on this line of reasoning:

- *Entering level 0:* This was once a radical change as it included the introduction of computers to the design workplace. This has now changed, as the use of computers in society has progressed. Still, there are companies with some staff still working manually for the most part.
- *Stepping up to level 1:* Design work requires further investments in software, training and technical solutions. For designers, level 1 means moving from “drawing lines” towards “object-based” working. Though acknowledged as “big steps” in a monetary sense, and in terms of challenging the drawing design identity of designers, work at levels 0 and 1 still mimics the traditional drawing-based processes. Such a change has also been undertaken, and benefits have been realized, by many of the respondents from the A, E and C companies interviewed. However, it should be noted that though working with a model themselves, the delivery from A and E companies here is typically a “drawing.pdf” (rather than a digital model). This “flattening-of-models” supports other stakeholders' current way of working, calling for no further changes in the following phases in the construction process. Whereas this makes the move less complicated for the single company, it renders no additional change (or subsequent BIM benefits) downstream.
- *Progressing to Level 2:* The move from level 1 to 2 is continuous, rather than stepwise, as BIM models are progressively provided with more information, and not just geometric information. Thus, information may come from several collaborating disciplines to form “islands of increasingly more complex information”. The continuous change depends on the level of collaboration with project stakeholders, and the exchange of information between them. Yet, levels 1 and 2 still support the (traditional, and still dominant) linear way of working, with established roles, deliverables, incentives and business models. The type and amount of information contained in the BIM model is frequently what the client (procure/demand from suppliers) asks for, and the move from level 1 to 2 in this respect is generally project related. Respondents aiming to be at the forefront of BIM seem to refer frequently to being prepared to develop and work with the kind of models that clients might come to demand in the future.
- *Transforming to level 3:* [13] noted that BIM adoption at this level is more complex. Our findings support their call for more attention to considerations beyond the frequently focussed technical enablers. Indeed, level 3 represents a fundamental change, challenging current ways of work, not only from a technical point of view but from a social one too. To carry out integrated work at level 3, radically leveraging the benefits of BIM, calls for a radical change to current roles, processes, contractual and non-contractual relationships, legal agreements, and potentially comes with the introduction of new business models. Subsequently, in the loosely coupled system of construction work, benefits associated with high BIM maturity, corresponding to level 3 in the model of Bew and Richards [15], are restrained by an inherent dependency on network transformation for their realization, that is, changes beyond the control of single organizations or disciplines.

Findings suggest that different types of projects may benefit from being operated at different maturity levels of BIM. The underlying assumption in much BIM-related research of level 3 as the common vision for all to strive for must, subsequently, be discussed and problematized. Indeed, current ways of work and organization of construction projects may be more suitable to meet the customer's requirements and needs, for example where high flexibility in design and implementation is a priority, and where level 3 as a concept does not work. At the same time, from a building life-cycle point of view, BIM level 3 is understood to facilitate lifecycle management (see e.g. Ref. [8] and adopting in full a life-cycle perspective requires integration and collaboration and a new way of working regardless of BIM.

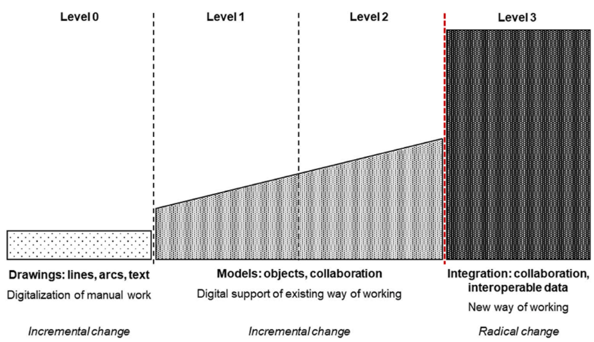

Fig. 2. Conceptual description of the digital maturity needed for different BIM maturity levels. A colour print is recommended for better understanding this figure. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

As discussed above, transformation into level 3 is a major step and would require changes in fundamental structures throughout the value chain. However, it should be noted that individual companies or constellations of companies have managed to address these barriers by challenging the current sector logic. For example, industrialized house building companies have changed their role in the value chain by integrating design and production in a product focus rather than a project focus, and with a supply driven logic rather than a client driven logic (e.g. Ref. [44]. Another example covers contemporary forms of contract and collaboration formats, such as clients taking a more active information management role by the support of BIM management consultants, and partnering (e.g. Integrated Project Delivery, see Refs. [6,14] where incentives are given to reach common goals by integrated ways of work with information and digital solutions in the design and production process.

However, elaborating on the proposition illustrated in Fig. 2, additional reasons for BIM benefits not being realized to their fullest potential, or even at all, could be found in the (expected) role of clients and the leverage of BIM for business-development purposes by supply-side actors.

It is suggested that clients are critical drivers for implementing BIM in the AECO sector, both in literature (see Ref. [39] and Table 3) and among the respondents (see sections 4.1.3 and 4.4.4). This agrees with the structure of loosely coupled systems in the industry, often used as an argument for more and clearer client requirements and control to drive change. A, E, and C company respondents, who saw themselves as relatively BIM mature, highlighted how demands from clients for the use of BIM, both in projects and facilities management (FM), are crucial for the respondents to advance their BIM use and offerings. The idea of the client as a driver for BIM implementation relies on the assumption that clients have the knowledge and ability to define relevant BIM-related requirements both for managing and coordinating projects (during planning, design, and construction) and for supporting operation and maintenance (O&M). Ultimately, it means that the client should require level 2 or 3 BIM for projects and detail what FM-related information is to be delivered at the end of the construction phase; then, the A, E, and C company actors could supply the information accordingly. However, our interview findings indicate that this does not reflect current practice. Instead, A, E, and C company respondents generally described how they use BIM for their own benefit and what they, if required by clients, could offer projects in terms of design-related and (to a lesser extent) construction-related benefits. O company respondents, in their turn, also essentially took a project perspective of BIM benefits (with a particular focus on new-build projects) and, being the least BIM mature actors in the study, commonly pointed to suppliers to help them find and realize potential benefits that might exist for O&M. In their role as clients, they recognized the benefits of using BIM in projects, but models, data, and information produced in the project were typically lost in their movement from their client role to their facility manager role, and poorly utilized to support O&M. As a result, most realized benefits were related to the project, and almost none were related to FM. Materneh et al. [45] recognized that the different information needs of FM and the project, and the interoperability issues between BIM and FM systems hamper the use of BIM to support FM operations. A dilemma appears to exist concerning the realization of BIM benefits for O&M suggested in literature [9,10] and among the interviewed respondents. First, A, E and C companies looked to O companies, which operate at the lowest maturity of BIM, to request BIM-related activities. Second, O companies asked the more BIM mature A, E and C companies, who arguably have less insight into the real estate industry, to propose and offer solutions based on BIM work. To overcome this dilemma, tighter coupling between the client and the facility manager role of O companies and increased BIM competence among them to better understand what BIM-related demands should be defined and how was proposed by some respondents. Another suggestion was that A, E and C companies should increase their knowledge of the needs and requirements of FM and then develop offerings supporting O&M benefits.

The client's strong project focus should imply a clear and strategic set of requirements to achieve all conceivable expected project benefits. However, this is hampered by the generally low BIM competence among clients, and they rather rely on what the suppliers can, and are willing, to do. From the supplier's perspective, some of the realized benefits facilitate and support the suppliers' work, which is a strong driving force in using BIM but, overall, most of the benefits are project-related and respond to current client demands. Related to this, the findings lack discussions about BIM in relation to future business opportunities including developing new business among A, E and C companies. Notably, none of the respondents described how they had converted delivered benefits into economic profit for their company. Suppliers, of course, deliver value to projects, but it seems they have been unable to create business with that value. In that sense, our findings seem to confirm the findings of [8] study on BIM adoption in the UK construction industry, stating that implementation of BIM at the highest maturity does not necessarily lead to more business. The lack of business perspective also relates to the more long-term unrealized benefits that arise beyond the project, such as O&M-related benefits and the ability to work with LCA and other lifecycle-related perspectives, that could potentially form the basis for new business for A, E and C companies [16]. explained the lack of realization of these benefits with an unclear nomenclature, but our findings rather indicate shortcomings in translating value into business. A few respondents from A and E companies in Finland and Norway described how they had offered O&M benefits in some special projects, but this had been done in collaboration with large government clients with good BIM competence who could drive development. A few examples can also be found where A and C companies reflected on the potential to offer *(inter alia)* "BIM-supported LCC and/or LCA". However, most clients seemingly do not have the competence to realize O&M benefits, and none of the respondents actually managed to realize BIM-supported LCA. Whereas the importance of clients to further the use of BIM has been highlighted (e.g. Refs. [4,39], this discussion raises questions about the prevailing one-way view that client demands are the way to drive BIM implementation and to realize BIM benefits. The ability and drive from A, E and C companies to work more proactively is an area that needs further research, and where a greater breadth of research disciplines probably need to collaborate. This proposed area of research includes the possibility of offering solutions instead of waiting for requirements, building business models to both benefit A, E and C companies' development of services, and benefit their customers by providing new business value.

Rather than creating new business value and developing new business models, it seems common for realized BIM benefits to result from working "within current practice". That is, expected benefits have been realized where an already established way of working can be supported by using BIM. However, realizing BIM benefits from supporting sustainable building beyond a design stage energy analysis may require a new way of working, stretching beyond maturity levels 1 and 2 which do not support cross-disciplinary integration of information or work beyond current practice. Though continuously larger islands of digital information have been, by some actors, created and collected in BIM on what can best be described as a continuum from level 1 to level 2, these islands do not, by themselves, introduce new ways of working. Such progressively expanding islands of information do not support more holistic sustainability analysis. Moreover, there is too little knowledge among lead users and BIM developers of the potential in supporting a lifecycle perspective of the built. Similarly, there is too little knowledge regarding environmental analysis such as LCA among building practitioners in general, and thus, too little knowledge on what to support with BIM (c.f. [5], how to support it, and how current work practice needs to, or could, be restructured. Taking LCA as an example, it is typically carried out *ex post* rather than *ex ante,* whereas BIM benefits, such as simulating different building design scenarios before deciding on the final alternative, assume the opposite. To realize these benefits would call for new ways of working but also the recognition of value associated with such a change of practice. Supply-side actors offering BIM-supported *ex ante* LCA benefits (i.e. presenting new business opportunities to clients) would imply not only the realization of BIM benefits but also the realization of potential new business value.

6. Conclusions

6.1. Proposed explanations for current state of realization, and subsequent implications

It is evident from interviews (see findings in Tables 5–8) that realized benefits occur in individual organizations' project-related work, mainly at companies involved in the design process. This indicates that the main drivers for current BIM use are the realization of project-related benefits rather than long-term benefits related to building lifecycle management (see expected but not realized benefits of BIM in Table 9). Unsurprisingly, interviews show that the benefits have been realized "within current practice". Yet, fully BIM-based project management (corresponding to maturity level 3) and using BIM for lifecycle management to support sustainable building implies developing and implementing an entirely new practice within AECO companies (see Fig. 2). From these ideas and the discussion presented in section 5, we propose that explanations for why certain benefits suggested in literature have been realized, whereas others have not, may be found in:

- what the highest common degree of BIM maturity is among companies cooperating within the same project, where "the highest common degree" is affected by state of practice in the sector (network level)
- the assumption of integration, collaboration and interoperable data i.e. the highest BIM maturity (level 3), to realize building lifecycle benefits, including operation and maintenance benefits and sustainability benefits
- the radical change needed at both the company level and on the network level i.e. network transformation, to realize fully any benefits associated with BIM maturity level 3 (as illustrated in Fig. 2)
- the ubiquitously assumed role of clients as drivers for implementation of BIM in the AECO sector which pushes the realization of strategic benefits [12] for AEC companies, i.e. business development by supply-side actors, out of focus

Securing the full benefits of BIM, including to support the societal strive to achieve the sustainable development goals, goes beyond the control of single organizations, project organizations or disciplines. Therefore, these explanations imply a need for better acknowledgement of multi-disciplinary competencies within and beyond the traditional disciplines i.e. integrating competencies in BIM use, facility management and sustainability. Another implication of these explanations is a need for changes regarding organizational, contractual and commercial aspects in sector/network-level BIM development. In this regard, we also argue that the radical changes assumed to achieve level 3 BIM calls for further exploring incentives for such a transformation beyond the more technology-driven implementation roadmaps proposed in previous studies (e.g. Ref. [8]. In addition, our proposed explanations imply that common governmental directives aimed towards certain actors (typically the client) may not suffice to implement and realize the benefits of state-of-the-art BIM. For example, a greater supply-driven logic among suppliers of BIM expert services, such as consultants, contractors and material suppliers, may be needed to realize current BIM potential and to further its development.

6.2. Limitations and suggestions for future studies

The presented research is based on an interview study exploring the gap between benefits proposed by state-of-the-art BIM and their realization in mainstream AECO industries. The research acknowledges gaps in BIM maturity among companies cooperating in the project-based and network-dependent AECO industries in northern Finland, Norway, and Sweden. Being exploratory and qualitative in nature, it should be noted that proposed explanations and subsequent implications are subject to further research. Indeed, whereas technological developments are moving fast ahead, indications are that adoption lags behind, and future studies are strongly advised to address this gap further. In this regard, our findings provide an argument for extending BIM research beyond the currently prevailing technology-driven approach to include socio-organizational and process aspects of benefits and adoption. In particular, we call for more business development-oriented research regarding BIM state-of-the-art technology and use. Moreover, we propose the need for more real-world case studies focussing on the possibilities for BIM-supported facility management (in line with [7,45] and sustainability practices.

Author statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

More detailed data in compiled, processed, and anonymized tabular form is available in translation and can be provided on request.

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