www.itcon.org - Journal of Information Technology in Construction - ISSN 1874-4753

TOWARDS AN IMPROVED FRAMEWORK FOR ENTERPRISE BIM: THE ROLE OF ISO 19650

SUBMITTED: June 2022
REVISED: November 2022
PUBLISHED: December 2022
EDITOR: Robert Amor
DOI: 10.36680/j.itcon.2022.053

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SUMMARY: *Enterprise BIM aims to optimise business management and asset management throughout the life-cycle of buildings and infrastructures. This follow-up study of the Enterprise BIM concept analyses the potential for international standardisation, mainly focusing on the contribution of the ISO 19650 standard series to further development. The study explores how key ISO 19650 concepts related to different types of information requirements, levels of information need, and common data environments can help strengthen Enterprise BIM. As such, the paper presents an in-depth analysis of how the ISO 19650 series and several adjacent standards can provide a further means of facilitating information management within the Enterprise BIM concept. The study uses a customised Zachman framework by adding the necessary perspectives from ISO 19650 and Enterprise BIM. The paper adds increased knowledge related to understanding the standard series parts 1, 2 and 3 and showing how they can be implemented in an enterprise structure. Based on the ISO 19650 framework, the study emphasises the importance of linking the information requirements to the various information needs of multiple end-users. At the same time, the paper provides new knowledge by showing that the information flow in the operational phase is far more nuanced than in the delivery phase, suggesting that information management must be considered in a completely different light from what previous research shows.*

KEYWORDS*: Asset information model (AIM), Asset management (AM), Building information modelling (BIM), Common data environment (CDE), Enterprise BIM, ISO 19650, Level of information need (LOIN), Operation*

REFERENCE: *Bjoern Godager, Knud Mohn, Christoph Merschbrock, Ole Jonny Klakegg, Lizhen Huang (2022). Towards an improved framework for enterprise BIM: the role of ISO 19650. Journal of Information Technology in Construction (ITcon), Vol. 27, pg. 1075-1103, DOI: 10.36680/j.itcon.2022.053*

1. INTRODUCTION

While Building Information Modelling (BIM) has proved its worth in the design and construction of built assets, owners continue to struggle to reap the benefits of BIM for asset management (AM) purposes (Love et al., 2014), Patacas et al., 2020). Among the reasons given for the disruption of information flows from design and construction to AM include non-consistent terminologies and taxonomies, inadequate specification of requirements, confusion over the level of information needed, and a lack of interoperability between different information systems (Patacas et al., 2020, Heaton et al., 2019, Jahanger et al., 2021, Jupp and Awad, 2017, Kassem et al., 2015, Tsay et al., 2022). Furthermore, deficiencies in digital literacy, imprecise information requirements for owners, and absent information and software protocols and standards lead to project data being disorganised (Jupp and Awad, 2017, McArthur, 2015. Making matters worse, information management in the built environment is often fragmented as temporary project organisations and project teams struggle to establish common data environments (CDE/ecosystem of CDEs) for purposes of data and information exchange (Patacas et al., 2020). All this results in unnecessarily expensive and unsustainable projects and ongoing processes for each asset.

The main problems are the construction industries' failure to organise information (Smith and Tardif, 2009) and their inability to consider the whole value chain of assets (Jupp and Awad, 2017, McArthur, 2015, Kassem et al., 2015, Chen and Jupp, 2018). This situation needs to change to produce and share information more efficiently and increase its utility for the operational phase of built assets. Thus, simply applying BIM technology in design and construction without addressing the above issues implies that the information is unlikely to be usable for AM (Sacks et al., 2018). This is where the emerging concept of Enterprise BIM seeks to contribute.

Enterprise BIM is an integrated concept seeking to enable a stable information flow serving multiple information needs during the value chain of a portfolio of built assets (Godager et al., 2021, Evjen et al., 2020). The goal is to enable organisations to realise more value from their built assets by providing timely, accurate, and detailed information about their buildings. The Enterprise BIM framework entails establishing a CDE ecosystem and corresponding information management guidelines to support the various information needs that arise during AM. Extending the utility of building information beyond design and construction to include AM by applying Enterprise BIM or similar concepts is likely to benefit the whole architecture, engineering, construction, operation, and ownership (AECOO) industry (ANZGuide, 2019).

However, a precondition for this vision to become a reality is that the appointing parties (owners and their clients, including asset managers) specify their information needs, data quality, and information deliveries in a more organised, standardised, and transparent way (Jupp and Awad, 2017, Smith and Tardif, 2009, ANZGuide, 2019, ISO, 2018c). Such a structured process will improve collaboration and project deliverables and support ongoing AM practices (ANZGuide, 2019, Becerik-Gerber et al., 2012, Kiviniemi and Codinhoto, 2014). Additionally, only when building information helps the information needs of business decisions in real asset portfolio management (ANZGuide, 2019) do the benefits of BIM come within reach of AM. Succeeding in this would make building information available for daily use, covering both foreseen events (e.g., planned or reactive maintenance, error reductions, rehabilitation, renewal, and decommissioning) and unforeseen trigger events (e.g., water or fire damage) concerning assets (Godager and Mohn, 2022).

Standardisation and clear frameworks are at the same time crucial to achieving such a comprehensive goal (Smith and Tardif, 2009, Godager et al., 2021, Borrmann et al., 2018, Jang and Collinge, 2020). Recognising the need for improved digital information management in the AECOO industry, policymakers and standardisation bodies have taken the initiative and issued a range of new standards (WEF, 2016, Bolpagni and Hooper, 2021). Examples include a series of ISO standards aimed at improving the organisation and digitising building information in the construction industry through the value chain of assets. Given that non-consistent terminology, taxonomies, and inadequate information are considered inhibitors of information management in the AECOO industry, then improved standards might prove helpful (Patacas et al., 2020). Moreover, the Enterprise BIM framework for AM might be informed by these standards to ensure that all actors have a shared organising vision of how their information systems can be utilised (Godager et al., 2021, Agarwal et al., 2016).

Taken together, today's technologies, with their potential for vertical integration, the Enterprise BIM framework, and recently issued ISO standards provide a starting point for standardised and holistic processes supporting the effective working and sharing of digital asset information. One standard series, in particular, the ISO 19650 series (ISO, 2018c), has been developed over several years to improve the use and digital sharing of building information

throughout the value chain of assets across industry standards. In addition, as a framework standard, the ISO 19650 series links information management and assessment of the United Nation's (UN's) goals for sustainable development (United Nations, 2015).

Only a limited number of research studies examine the potential of the ISO 19650 framework to support the requirement definition for asset information required by end-users in the operational phase. Moreover, too many stakeholders are being asked to adapt their work processes to the ISO 19650 standard through generic contractual requests with too general terms and information requirements (Robitaille et al., 2021). Moreover, there is still a need for more research on the role and implications of ISO 19650. While some studies consider the delivery phase, such as Çekin and Seyis, 2020 and Luedy et al., 2021, very few studies consider the operational phase. Moreover, only a few case studies provide empirical evidence about how the ISO 19650 framework links to life-cycle applications (Tsay et al., 2022). The operational phase and the inclusion of the roles involved (e.g., asset owner/operator, project client, asset manager, design team, construction supply chains, equipment manufacturers, systems specialists, regulators, and other types of end-user) remains an understudied perspective in present literature (Sadrinooshabadi et al., 2021, Kijak, 2021, Scheffer et al., 2018, Sacks and Pikas, 2021).

The main aim of this paper is to assess how current international standards (ISO 19650) can contribute to improving information management practice to support the entire value chain of built assets while further developing the Enterprise BIM concept. As such, this study will answer the following research question: How can the ISO 19650 series support the information and business management of Enterprise BIM?

To answer the research question, the paper is organised as follows. Section 2 focuses on key concepts in ISO 19650 series and related standards relevant to Enterprise BIM. Section 3 clarifies the research methodology. Section 4 presents the main ideas of the Enterprise BIM concept and the Zachman framework (Zachman 2008), which are used to inform the analytical part of the paper. Section 5 presents the findings of how the ISO 19650 standard can support Enterprise BIM. Section 6 discusses the findings, and finally, section 7 concludes the paper.

2. ISO 19650

ISO 19650 is a standard series for managing information over the whole life cycle of a built asset using building information modelling. The ISO 19650 standard series currently consists of 5 parts, where parts 1, 2, and 3 are considered the most important for Enterprise BIM. Part 1 (ISO, 2018c) outlines the concepts and principles of information management in BIM. Part 2 (ISO, 2018d) defines the requirements for information management in the delivery phase. Part 3 (ISO, 2020f) specifies the requirements for information and a collaborative environment during the operational phase of assets and influences digital practice linked to individual projects and the enterprise's overall digital approach. In addition, this section also makes it possible to take care of assets that the users of the asset are adding during use. Part 4 (ISO, 2022) is under development, but the goal is to provide processes and criteria for decision-making when executing the information exchanges. Part 5 (ISO, 2020b) focuses on the need to solve a security-minded approach to information management. However, other complimenting frameworks must be added to take care of wholes related to supporting the information security and safety needs of Enterprise BIM. Together the frameworks of ISO 19650-2 (delivery phase) (ISO, 2018d) and ISO 19650-3 (operational phase) (ISO, 2020a) describe the considerable scope available to meet the specific requirements of individual projects and organisations. These two parts have different contributions and require different approaches.

Some barriers to more integrated project delivery that enable the Enterprise BIM concept can be overcome by embracing current international standards (Godager et al., 2021). For instance, ISO 19650 provides a common framework for cooperation, communication, requirements, exchange, and management regarding all information between all actors who take care of all executive roles in the value chain of assets. Furthermore, the standard sets out the recommended concepts and principles for information management and business processes across the whole built environment sector, and it also seeks to support information management over the entire life-cycle of the built environment of assets (ISO, 2018c). The ISO 19650 standard series is flexible and role-focused and can be adapted to organise assets and the users of assets and construction projects at any scale and complexity, covering a wide range of potential procurement strategies (ANZGuide, 2019).

Beyond ISO 19650, there is a range of upcoming and existing international standards aimed at improving the quality of products, processes, and information delivered by the AECOO and other industries. For instance,

implementing the ISO 9000 series (ISO, 2015a, ISO, 2015b) has contributed significantly to the organisation of quality-related data in construction, and ISO 19650 clarifies the relationship with other adjacent standards such as the ISO 9000 series and the ISO 55000 series (ISO, 2014a, ISO, 2014b). A description of the concepts and processes considered to constitute good practice in project management in AECOO is standardised in the ISO 21500 series (ISO, 2012). Moreover, AM is standardised in the ISO 55000 series. ISO 8000 (ISO, 2018a) has standardised data quality in construction (ISO, 2018a, ISO, 27000) and established a standard for information security management (ISO, 2018f, ISO, 2013a, ISO, 2013b), and ISO 31000 (ISO, 2018e) has established a risk management guidelines in AECOO (ISO, 2018e). The concept of information containers organising data drops of digital construction information based on linked data, including heterogeneous data from any domain in any format according to linked data principles, has been introduced as part of ISO 21597 (ISO, 2020c, ISO, 2020d). ISO 16739 (ISO, 2018b) specifies a conceptual data schema using Industry Foundation Classes (IFC). ”Level of information needs” (LOIN) is introduced in ISO 19650. Nevertheless, it is gratifying that a separate LOIN standard is currently under development (CEN, 2020), inclusive of a ”data specification schema” to make LOIN machine-readable (EN 17412-3). This LOIN standard will be related to EN ISO 23387 (data templates) (ISO, 2020f), which, through revision, will be less bound to IFC and then more open to implementation, such as semantic solutions. This upcoming revision of EN ISO 23387 is planned to establish the necessary standard terms and definitions, including LOIN. The forthcoming linked data standard prEN 17632 and the revision of EN ISO 12006-3 (IFD) (ISO, 2007) are planned to work in conjunction with these. In addition, the ISO 14000 series (ISO, 2015c) establishes an environmental management system seeking to improve the environmental performance of construction organisations.

Some of the above standards have had an extensive influence on industrial practices. Considering which of the standards focuses most on strengthening the links between design, construction and AM, we decided to concentrate on the ISO 19650 series in this paper. The reasons are that most standards focus on other aspects of the project life-cycle at times, even unintentionally contributing to breakdowns in information flows. For instance, using open, standardised formats is very good, and ISO 16739 (ISO, 2018b) is currently the basis for open, standardised exchange. Nevertheless, in Enterprise BIM, IFC is only one of many ISO standards needed during both the delivery and operational phases.

Moreover, to handle customised digital twins, IoT, sensory and real-time data (all need BIG-data treatments), information solutions must be flexible and interoperable and ensure data quality, safety and security. Furthermore, the solutions must be easily searchable, scalable, and profitable. In their current versions, ISO 23386 (ISO, 2020e) and ISO 23387 (ISO, 2020f) are too related to the EXPRESS language. However, the upcoming revision of these standards deals with product data templates (PDT) without connecting these to the building smart Data Dictionary (bsDD). Therefore, BsDD may inhibit integrating all the essential factors related to AM.

Since the Enterprise BIM concept, introduced in section 4 of this paper, seeks to provide an information infrastructure for sharing updated information based on semantic web technologies, improving it based on the ISO 19650 series could be worthwhile. Some of the ISO 19650 concepts could help future-proof the Enterprise BIM concept and increase its applicability in international contexts.

Three of the most central concepts in ISO 19650 are AM, LOIN, and CDE:

1) AM: ISO 19650 merges the concepts of facilities management (FM) and asset management (AM). FM and AM are distinct disciplines, although both are concerned with managing physical assets and services in the built environment. Furthermore, AM and FM have developed their standards and languages of preferred terms (ISO, 2018c). However, developments in digitalisation have helped to erase this clear boundary between AM and FM and have provided new opportunities in the form of integrated solutions which cross the FM and AM boundaries. In future digital information management, the executive roles (agreed in contracts) that apply to the various buildings will perform what will be served as the FM part and the AM part.

2) LOIN: The ISO 19650 series has established a consistent methodology for specifying and utilising the purpose-driven concept of ”level of information need” (LOIN) together with information deliveries using building information modelling (BIM) (ISO, 2018c, ISO, 2018d, ISO, 2020f). Depending on the phase, environment for use, and timing, the LOIN principles define the extent and required level of quality, quantity, and granularity of geometrical information, alphanumeric information, and documentation to support specific work performances and professional roles (ISO,

2018c, Borrmann et al., 2018, ISO, 2018d, ISO, 2020f, ABAB, 2018). The appointing party establishes the method for defining LOIN as part of the project's information standard (delivery phase) or asset information standard (operational phase).

New areas support the geometrical part of these specifications to consider the information needs by adding the elements of object detail, dimensionality, location, appearance, and parametric behaviours (ISO, 2020f). All the above ensures that the various information requirements are based on the necessary information to perform individual roles in operational processes.

Furthermore, the LOIN principles will be strengthened by developing a separate LOIN standard series (CEN, 2020). A fundamental principle for achieving a successful and profitable use of BIM in ISO 19650 is that LOIN is determined according to the purpose and reason why the information is necessary for each information delivery (ISO, 2018c). This requires essential competence in individual roles. At the same delivery milestones and information, containers should result from one or multiple information requirements defined for each purpose using the LOIN framework (Bolpagni and Hooper, 2021).

LOIN could be determined with a range of metrics or assessments. E.g., two complementary but independent metrics can define the geometric and alphanumeric content in terms of quality, quantity and granularity. Such LOIN approximation is fundamental to enabling the successful information exchange of every information deliverable (work order at all levels). Everyone who does something in buildings is an end-user, including professionals without specialist competence in information, communication and technology (ICT) and BIM. The information requirements must consider these different groups of end-users. Fig. 1 is a result of combining all the purposes of the LOIN principles. To be feasible, a customised collaboration solution (CDE) is crucial. Here the different milestones are numbered, and the most relevant questions and elements to take care of are indicated. For each information need, such a purpose-driven procedure asks what, which, how, and who.

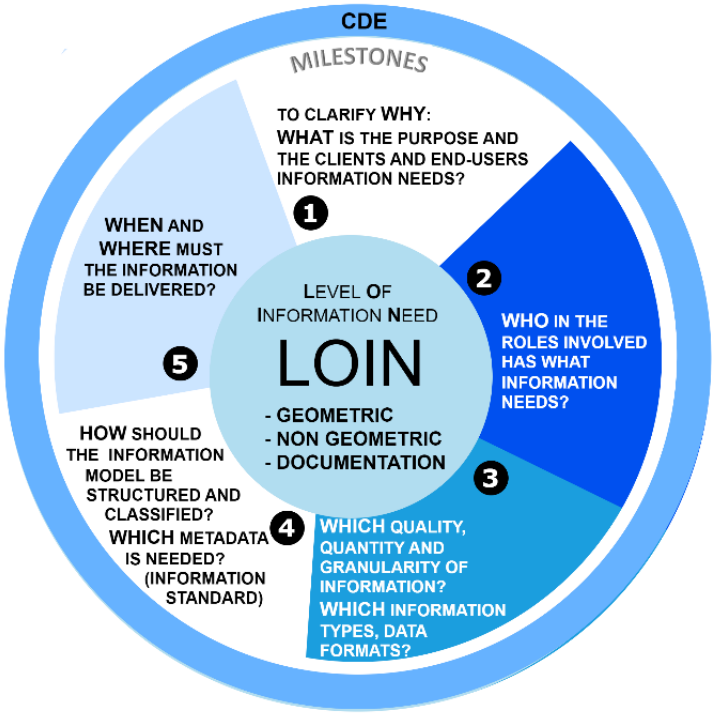

FIG. 1. Aspects of managing the collaborative production of information using the LOIN principles and a CDE, developed with inspiration from (ANZGuide 2019).

3) CDE: Another essential concept in ISO 19650 is the adoption of the Common Data Environment (CDE) or, more realistically, the CDE ecosystem concept. In CDE, construction project information can be stored and managed. Reliable and stable information flows, satisfying information needs of well-established roles and efficient information management are crucial for enterprises seeking to use digital asset data. CDE allows for a transparent and predictable information flow facilitated by information systems across organisational boundaries. At the same time, ISO 19650 strongly emphasises that all actors involved clearly understand their role and the overall information management process during the asset's value chain (ANZGuide, 2019). Moreover, the ISO 19650 standard series emphasises sustainability in the sharing of information during an asset's life-cycle (ANZGuide, 2019) while supporting environmental, social, and economic sustainability through the provision of processes for standardised electronic purchase information such as tracking and the documentation of products used in assets.

The ISO 19650 standard series has been developed based on a consensus by international experts and represents a good first version for developing best practices and standardising processes. Moreover, it provides a holistic frame for BIM-based information management, including exchanging, recording, versioning, and organising, for all actors throughout all stages of the asset's value chain (ISO, 2018c). The ISO standard aims to help facilitate the future digital cooperation and sharing of building information based on the client's business needs and the derived information requirements. In summary, the ISO 19650 standard aims to provide (1) information requirements based on the information needs of businesses, deliveries, users, and the authorities; (2) a more standardised and specific information flow for collaboration between different parties in the industry; and (3) better quality assurance of information (ISO, 2018c). During the development of the first version, the standard's publication was given priority, although it had some contradictions. However, it has already been decided to revise ISO 19650 as new experience is gained in its application.

The last part of this section focuses on the meaning and understanding of three critical concepts in the ISO 19650 framework. These are the different information requirements and their functions (section 2.1), the project information model (PIM)/asset information model (AIM) (section 2.2), and how the information requirements are related to PIM/AIM in the delivery and operational phase (section 2.3).

2.1 Information requirements and their functions

Information requirements should be developed in a specific order and with the necessary inclusion of the involved actors' roles in their various processes to gradually build up the details and thus fulfil the purpose of the project and the recipient's (specifiers') use of the information in the organisation. At the same time, the requirements must define how and when information must be replaced in the project/asset's life-cycle (ISO, 2018c, Bolpagni and Hooper, 2021). Some of the most essential of these different requirements are:

- The organisational information requirements (OIR) define the information required by an organisation (owner or operator) to achieve its organisational objectives across the asset portfolio and its various departments (ISO, 2018c). All organisations have their OIR, but in Enterprise BIM, it is the OIR of the owner/manager who is in charge, and the OIR of the asset users must take care of this. The OIRs explain the needs of AM at a high level and answer or deliver their organisation's strategic goals.
- Such requirements may arise from strategic business operations, AM, portfolio planning, regulatory tasks, or policy formulation. Organisations must therefore assess the information requirements of the operational phase before these requirements are determined in project deliveries. In Enterprise BIM, the OIRs should guide the asset information requirements (AIR), project information requirements (PIR) and exchange information requirements (EIR). The OIR of the enterprise/organisation must be clearly defined to achieve a well-functioning AIM. OIR explains the specifications for information required from the owner or manager to answer or inform an asset's high-level strategic objectives and business needs during its delivery and operation (ISO, 2018c, Borrmann et al., 2018, ABAB, 2018).
- According to ISO 19650, AIR defines AIM's content, structure, and methodology. AIR represents the information needed for critical decision-making in the operational phase to respond to OIR and describes the necessary information for creating an AIM. The AIRs must be related to the asset management work, agreements or instructions (Borrmann et al., 2018). AIR must thus include all

necessary building components to be incorporated into BIM (the modelling), their management, and associated maintenance procedures.

- Based on the OIRs, the PIRs collect information requirements during a design and construction project. They enable the appointing party's information requirements to be understood and identify what is necessary for the key decision points (Bolpagni and Hooper, 2021).
- EIR has a more complex structure because these information requirements need to be given in detail. EIRs define the purposes and function of information, information requirements, format, and the level of information needed by the appointing party's procedures applicable to PIR (for the project level) and AIR (for the operational level).

2.2 PIM and AIM

ISO 19650 uses BIM in the sense of Building Information Modelling. Further, it specifies/divides BIM into PIM for the delivery phase and AIM for the operational phase. Both PIM and AIM are structured repositories of information needed for making decisions during the entire life-cycle of a built environment asset (ISO, 2018c). PIM (comprising sets of information containers) should provide all the information required to carry out an asset's delivery phase (handover). PIM is input to AIM, which comprises documents, models, and structured data for the operational phase of an asset. AIM contains necessary information (documents, models, and structured data) to support the appointing party's strategic and ongoing management processes. AIM must be further connected to an asset management system and the impact of its asset management strategy and plans (ISO, 2020f). A successful AIM requires that the various roles and critical personnel (e.g., contract partners, managers and others associated with the individual building) be linked to the practical use of AIM.

2.3 Information requirements and models

The relationship between the various information requirements to satisfy PIM and AIM is described in Fig. 2. All these requirements are terms in ISO 19650, which should be linked to the different functions and roles and their information needs. For example, the OIR can be seen as owner/manager-centric at the strategic level, and the AIR is asset-centric at the AM level. Therefore, the AIR should inform PIR of the delivery phase, if assets existed before. Furthermore, all these requirements should be based on the LOIN premises for end-users. By doing so, the PIM from the project level (delivery phase) is more likely to be valuable in the AIM and further serve as a part of Enterprise BIM.

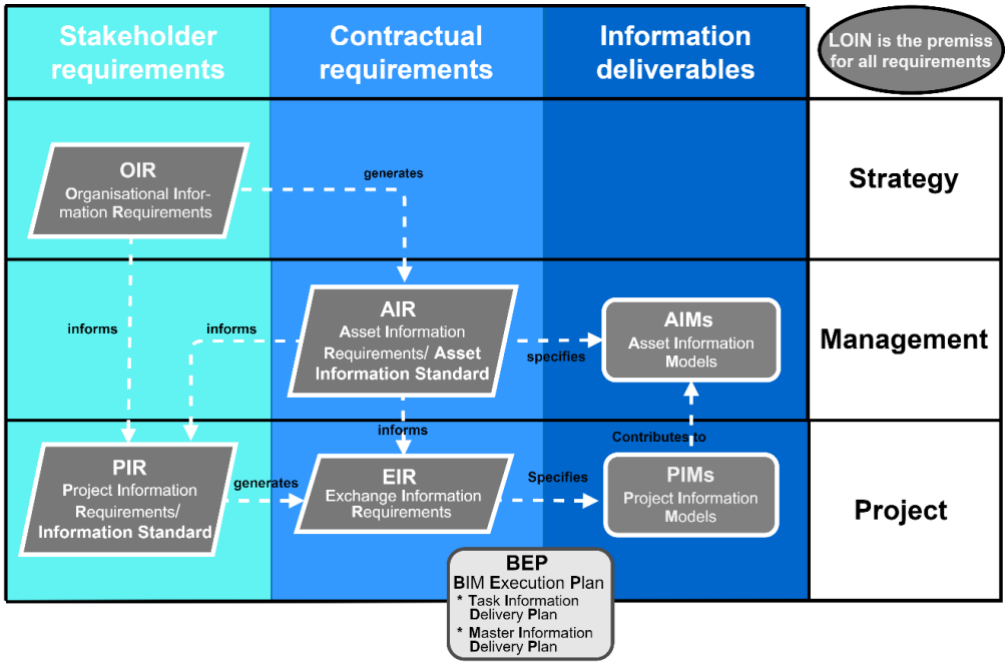

FIG. 2. Information management throughout the asset value chain, based on ISO 19650-1 (ISO, 2018c and Borrmann et al., 2018). The level of information need (LOIN) is the premise for specifying what should be considered in calculating all information requirements.

The LOIN principles ensure that only the minimum amount of information is required to respond to each relevant information requirement (OIR, PIR, AIR, or EIR), including information required by other appointed parties (ISO, 2018c, Bolpagni and Hooper, 2021). These information requirements must be linked to specified roles (e.g., society, owner, plumber, tenant, operator) and technical functions. These role-based information requirements must further support work performances in the operational phase.

The requirements can arise from strategic business operations, strategic asset management, portfolio planning, regulatory duties, and policymaking, which must also be linked to technical contract-related requirements. At the same time, it is necessary to establish a CDE ecosystem as a fundamental tool for implementing these requirements. Fig. 2 shows the relationship between various information requirements and information models produced and used across the asset value chain. The vertical division shows the links to the strategic (OIR), management (AIR, AIM), and project levels (PIR, EIR, PIM). The horizontal division of Fig. 2 (and in Fig. 3) represents the different views on the asset, which decisively influence the requirements and the resulting information models. It is crucial to link the AM operations to the OIRs and the AIRs, which in turn inform the OIRs and the AIRs, which in turn inform the PIRs and the EIRs (ANZGuide, 2019). Within Enterprise BIM, the strategic level must include digital information management. Such digital strategies must be developed because much of the AECOO industry is mainly analogue.

In the operational phase, the information requirements will mainly come from AIR, not PIR (cf. Fig. 3), and PIR is therefore removed from the figure. In unforeseen trigger events, both ISO 19650-2 (cf. Fig. 2) and ISO 19650-3 (cf. Fig. 3) can be activated. Projects of a certain size will also trigger ISO 19650-2. At the same time, only adapted, necessary content from PIM should be aggregated into AIM. However, PIM will be central in rehabilitation projects above a certain size. At the start of the delivery phase, a transfer of relevant existing information from the AIM to the PIM may give valuable information.

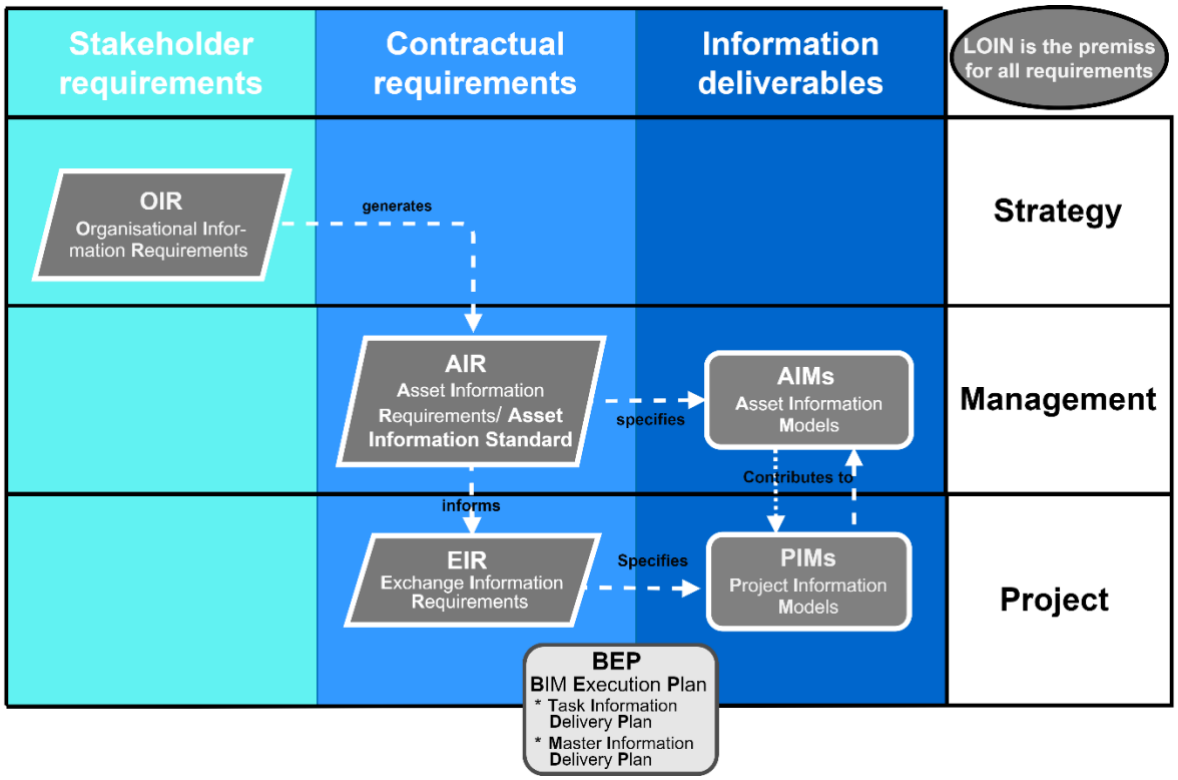

FIG. 3. Information management throughout the asset life-cycle based on ISO 19650-1 (ISO, 2018c) and ISO 19650-3 (ISO, 2020a). LOIN is also the premise for specifying what should be considered in all information requirements in the operational phase.

3. RESEARCH METHODOLOGY

This study has aimed to analyse how the ISO 19650 series' key concepts and principles can strengthen the development of a holistic and sustainable life-cycle perspective of the Enterprise BIM concept. Its main goal is to propose a reconceptualised or improved framework that will benefit the target groups, such as researchers, owners, decision-makers, ICT developers, and other players in the construction industry. Therefore, an integrative literature review (Torraco, 2005) has proved most appropriate. This research reviews criticises and synthesises representative literature to generate new frameworks and perspectives on a topic (Snyder, 2019). This method is a form of research that reviews, criticises and synthesises representative literature on an integrated topic to generate new frameworks and perspectives on a topic. Given the complexity of Enterprise BIM, its many target groups, different processes, and this study's goals, we have implemented an integrative literature review.

The authors have versatile experience in Enterprise BIM and standardisation over several years. These previous actions, research, and development experiences have assisted the interdisciplinary review approach by choosing the Zachman ICT framework (Zachman, 1987), a schema for organising enterprise architectural artefacts (see section 4.1). Zachman defines information system architecture by creating a descriptive framework from disciplines independent of information systems (Zachman, 1987). Due to the complexity of Enterprise BIM, we have developed a customised Zachman framework to organise and obtain an overview of the various contributions from ISO 19650.

Initially, the studies explored the state of the art in literature, standards, and websites to establish a sufficient basis for the research results. The study followed a four-step process to identify, collect and classify the literature, standards, commentary, and websites. First, the keywords used in the research process were: "BIM", "Building Information Modelling", "facility management", "asset management", "standard", "information requirements", "asset information model", "framework", "enterprise", "semantic web", "level of information need", "digital twin", "common data environment", "ontology", "enterprise modelling", "enterprise architecture", and "Zachman framework". Next, valuable standards and accompanying guides were searched and sorted separately. Secondly, keyword searches using combinations of the above terms were conducted in the Google Scholar, Scopus, and Oria search engines. Due to the little research related to the research question, we had to be creative. Academic papers, reports and guidelines have been used while drawing on what has already been reported in various contexts to make informed suggestions for future actions related to further improvements to the Enterprise BIM concept. Thirdly, after reviewing the downloaded papers, relevant papers were added from the bibliographies before standards and guidelines were selected and classified. To determine whether a study met the inclusion criteria for the review, the quality and content were assessed based on the general quality and the extent to which the content could contribute to answering the research question. The literature was mainly classified by one of the authors, while which standards to include in the review were assessed separately by two reviewers.

Fourthly, to assess the research question "How can the ISO 19650 standard series support the information management of Enterprise BIM?" the paper discusses potential from the following sub-areas: terminology and principles, the life-cycle needs of enterprises, the definition and use of "level of information needs" (LOIN) and corresponding information requirements, definitions, and assessments of BIM capability and BIM capacity, the establishment and use of the CDE/ecosystem of CDEs, and necessary support from adjacent standards, as well as the identification of missing standards for the full utilisation of ISO 19650. The study aims to make the overall knowledge more accessible to the target groups, such as researchers, owners, decision-makers, ICT developers, and other players in the AECOO industry. Therefore, the completed study has sought a systematic approach by linking primarily to the perspectives and roles involved, with support from the adapted Zachman framework.

4. ENTERPRISE BIM CONCEPT AND ZACHMAN FRAMEWORK

4.1 The Enterprise BIM concept

AM belongs to the operational use phase, and Enterprise BIM is the complete digital information bank linked to assets, cf. Fig. 4. The value chain for assets and Enterprise BIM only starts during construction after the physical products/building materials are built into an asset. Therefore, the product documentation is recorded continuously during the construction phase, and the various management systems only become operational when the construction period has ended. Therefore, part 3 of ISO 19650 (the operational use phase) becomes the central information part of the enterprise's BIM. Including the preparatory work in the asset's value chain/life cycle is

imprecise. However, the preparatory work such as needs analyses, design, planning and engineering is crucial for the asset to be sustainable (concerning finances, the environment and society for the owners and the businesses they will house.

Enterprise BIM promotes digital collaboration and the sharing of up-to-date building-related information and knowledge, allowing core businesses and building owners to exploit the potential of the data and information to achieve their organisational goals across disciplines and systems throughout the value chain of the built assets (Godager et al., 2021). Enterprise BIM is defined as "A virtual holistic representation of the life cycle of the built environment adapted for optimised business management, knowledge-sharing, and collaboration" (Godager et al., 2021). Enterprise BIM aims to establish holistic information structures that provide expanded support and utilisation to an enterprise's need for building-related information for the entire asset portfolio. The Enterprise BIM concept seeks to establish and handle all the digital asset information of the AM. However, business modelling should consider information about organisations outside the Enterprise BIM scope (cf. Fig. 4).

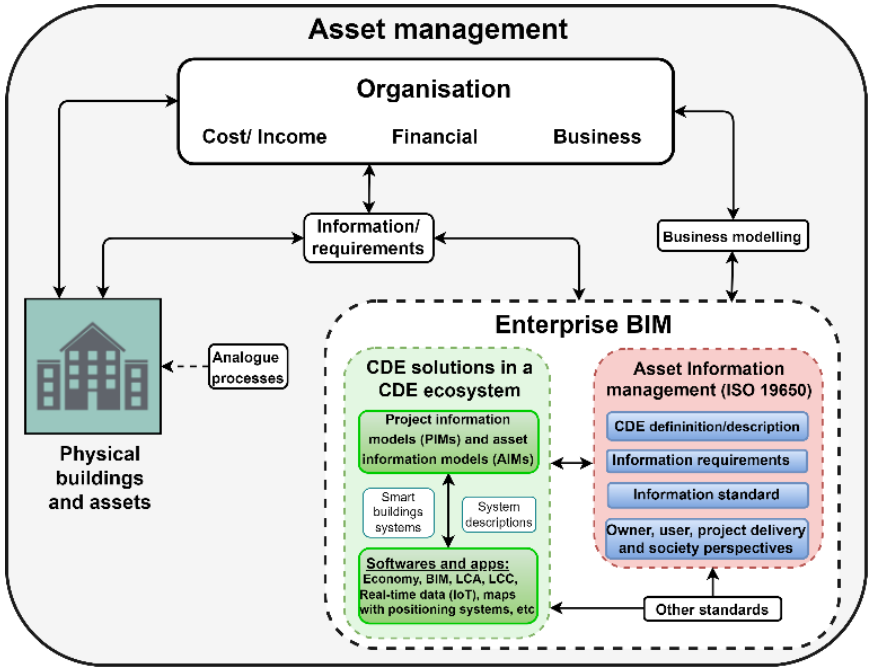

FIG.4. AM and Enterprise BIM. AM covers physical assets and digital representation and is linked together by information requirements. Enterprise BIM supports AM digitally.

The Enterprise BIM concept approach requires the industry to develop a broader focus than just the building process. From an enterprise perspective, the industry's products and services are part of a more extensive system (Smith and Tardif, 2009).

At the same time, reliable and necessary information related to different roles varies significantly for different assets, and efficient information management is crucial from an enterprise perspective. Therefore, for the AECOO industry to become more efficient, the flow of information and the digital collaboration and sharing between the parties in the AECOO industry must be standardised and made more specific, as well as directly linked to the schedule for procurement and execution.

What is part of an Enterprise BIM constellation can vary significantly in the number of assets, their size, and complexity. Often it includes more than one building, often both new projects and existing buildings simultaneously. Therefore, activity coordination is necessary to take care of strategic AM needs and the enterprise's other needs. In addition, Enterprise BIM supports the maintaining facilities and infrastructure networks and aims to support relevant end-users information needs. However, in the operational phase, the different information needs of the wide variety of end-users are still relatively overlooked. ISO 19650 has the framework to support addressing and specifying the information needs of these roles.

To manage the information in Enterprise BIM efficiently (cf. Fig. 4), Enterprise BIM requires a well-developed and flexible common data environment (CDE). It typically requires several CDE (CDE ecosystem) solutions that support effective digital interaction and information management for the entire value chain of the built assets (Godager et al., 2021). Such solutions are necessary to strengthen interoperability.

Enterprise BIM needs the foundation from ISO 19650 Part 1 (ISO, 2018c) and Part 2 (ISO, 2018d) for new delivery projects. Part 3 (ISO, 2020f) is especially essential for the operational phase of Enterprise BIM and pays special attention to this in the following:

- Its focus on digital information management enables the realisation of enterprises' information needs.
- Support for sustainable and environmentally friendly buildings and requirements.
- The link to new and existing enterprise systems.

One way to consider how the contributions from ISO 19650 can support the Enterprise BIM concept is by using a customised Zachman framework.

4.2 Enterprise architecture, Zachman framework and our adoption

An enterprise architecture (EA) is a formal description of a system or a detailed system plan at the component level developed based on organisational goals and overall business objectives guiding its implementation (Haes and Grembergen, 2009). An EA can show the structure of components, their inter-relationships, and the principles and guidelines governing their design and evolution over time. The Open Group's definition is: "Enterprise Architecture is about understanding all the different components that go to make up the enterprise and how those components inter-relate" (The Open Group, 2022).

Using an EA framework is to build a fundamental part of a future, holistic "road map" for the common understanding and alignment of a coordinated ISO 19650 implementation process. An essential sub-goal for Enterprise BIM is to create new "digital business" designs by blurring the line between the physical and digital enterprise.
Enterprise architecture (EA) can address two problems (Sessions, 2007):

- System complexity: organisations are spending more and more money building ICT systems; and
- Weakly developed business alignment: organisations are struggling and finding it challenging to keep these increasingly expensive ICT systems aligned with business needs.

The concept of information architecture describes the structure of a system, i.e., the way information is grouped, the navigation methods, and the terminology used in the system. Information architecture is typically associated with websites, intranets, online communities, and software, but it can be used in contexts with all information structures or computer systems (Barker, 2005). First, the reasons for doing this at the enterprise level are because of the complexity of Enterprise BIM and to have a key to overcoming religious wars concerning technological choices within projects. Secondly, it is to solve enterprise problems and provide a consistent and disciplined use of technology.

Typical EA key concepts are (Sandkuhl et al., 2014):

- Actors' concerns — interests that are critical to other actors.
- Principles — a univocal understanding of what is of fundamental importance for the organisation.
- Models — purposeful abstractions of reality.
- Views — to create a unique and comprehensive set of models that can be understood by all concerned.
- Frameworks — structure for selecting views.

The Zachman Framework meets the EA need in this research paper (Zachman, 2008, Zachman, 1987, Sessions, 2007). According to Zachman's vision, business value and agility are best realised through a holistic approach to system architecture that looks at all crucial issues from all perspectives (Sessions, 2007). Therefore, Zachman's framework is more like a taxonomy or methodology than a framework, having the highest taxonomy completeness, i.e., how well the methodology can be used to classify the various architectural artefacts (Sessions, 2007). However, within EA, it will be possible to select bits and pieces from other methods (e.g., Gartner or TOGAF) and modify and merge them according to an organisation's specific needs (Sessions, 2007).

The framework provides a way of viewing an enterprise and its information systems from different perspectives and showing how the business components are related. It can be used to model an organisation's existing functions, elements, and processes and help manage business change (Zachman, 2008). The Zachman Framework is not a methodology for creating the implementation but can be seen as a proactive business ontology describing the enterprise (Zachman, 2008). Because it is a classification framework with a basic structure about the scientific nature of any enterprise, it is often categorised as an ontology.

The typical Zachman framework is depicted as a bounded 6 x 6 matrix (Zachman, 2008). The original Zachman framework uses these six perspectives. However, to serve buildings, the societal perspective, the various phases of the buildings, and the diversity of end-users and in-use must also be treated separately. By adding these perspectives, Zachman's framework can also be applied to buildings and their use.

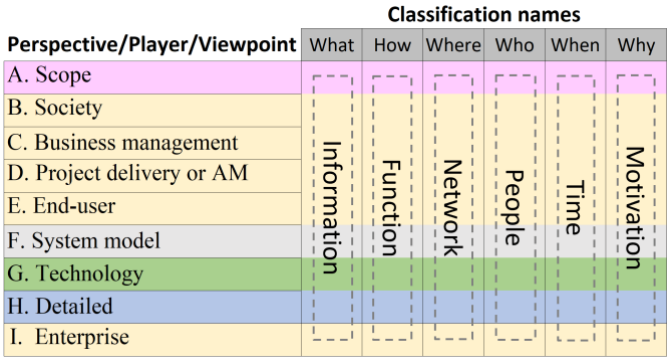

FIG. 5: Visualisation of the customised frame built on the Zachman framework.

In Fig. 5, rows A to H show the different actor's perspectives, while row I (Enterprise) proves the fundamental concept of transformation to reach the reality of the functional enterprise. Row I has the same colour as the four perspectives 2, 3, 4, and 5 because whatever the owners (business management) or the tenants have in mind (C) should be what is instantiated in the enterprise row (I) (Zachman, 2011). At the same time, we have also chosen to keep the same colour in rows B, D, and E, because these must work together with business management (C). Our adaption and results are described in section 5.

To provide an overview of "what", "how", "where", "who", "when", and "why" for all perspectives and classifications, a customised Zachman Framework is derived (Zachman, 1987, Zachman, 2008) to show how important elements of ISO 19650 can be linked to Enterprise BIM. With the increasing size and complexity of information systems, it is necessary to use such a logical architecture to define and control the interfaces and integration of all system components. To focus on the contribution of ISO 19650, we have developed a customised, descriptive Zachman-based framework. This framework specifies an overall information system architecture, where elements of ISO 19650 are visualised and can form a basis for current and future ICT solutions.

5. HOW THE ISO 19650 STANDARD CAN SUPPORT ENTERPRISE BIM BY USING THE ZACHMAN FRAMEWORK

This section is sub-organised according to our perspectives in an expanded Zachman framework (Fig. 5). It gradually leads to the interconnected and content-developed framework in Fig. 7 at the end of this section. We have tried to place the various contributions from ISO 19650 where they most logically belong, but this is balancing because much of the standard is relevant from several perspectives.

5.1 Scope

The scope describes the business context, such as type lists of inventory, processes, distribution, responsibility, timing, and motivation. It is necessary to know the business well to determine the scope. The information requirements need a link to the operational use of asset information. Furthermore, the information needs to handle critical asset-triggering events, namely start-up, acquisition of assets, planned maintenance tasks, renewal and renovation, call-off schemes for repairs in common areas, user needs and life-cycle processes. "Failure to define and express these requirements will most certainly result in change orders, delays in handover, delays in commissioning, inefficiency in operations and maintenance" (ANZGuide, 2019), p. 18.

The scope is very much related to identifying the information needs aligned with strategies and objectives and how to link these needs and different roles or functions in the enterprise. Furthermore, it is crucial to identify all the actors involved and their responsibilities, capability, capacity, and the information they need in their different process roles.

Fig. 6 is an extension of Fig. 4 and focuses on the asset information management principles organised in a CDE ecosystem. The figure shows the overall picture of solid contributions from ISO 19650 to the Enterprise BIM concept in a common data environment containing different CDE solutions.

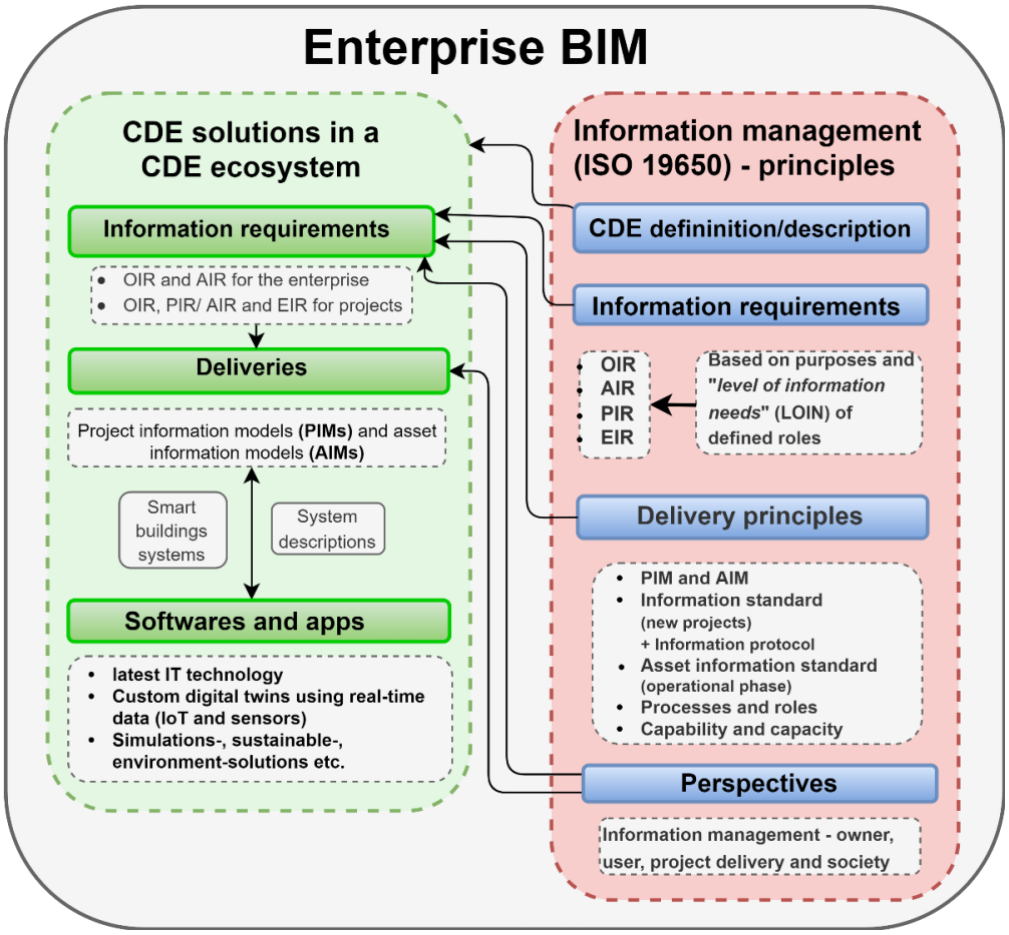

FIG. 6: Extended version of FIG. 4, focusing on the Enterprise BIM part.

5.2 Society's perspective

From a political and social point of view, the community's interests must be taken care of during the value chain of the assets, which is also central and essential in the UN's sustainability goals. Examples are political decisions, laws, area plans, building permits, and concessions (ISO, 2018c), but also rules regarding customer responsibility, the societal impact, and labour standards must be observed. At the same time, international environmental and climate decisions are increasingly important, and Enterprise BIM will support sustainable building processes and high-performance operations with fewer resources and lower risks. Therefore, OIR must also take care of these elements described above.

Part 6 of ISO 19650 (Health and Safety) is under development and beyond the scope of this paper.

5.3 Business management perspective

The owner's, manager's or tenant's/user's perspectives are to establish and maintain the asset or project's purpose and make strategic business decisions (Smith and Tardif, 2009) (ISO, 2018c). The operation of the enterprise is the reason a business exists, and a successful Enterprise BIM solution to support AM must have a long-term character. In any case, the overall purpose of all projects is to create value (Smith and Tardif, 2009, ISO,

2018c, ISO, 2014a). Before determining these values, it is essential to understand what is valued and what information is needed to support this value creation. These fundamental principles are critical to the ISO 55000 and the ISO 19650 series.

Across the asset's value chain, asset and project information are inextricably linked. ISO 55000 indicates the vital factors that enable organisational success (ISO, 2014a):

- the nature and purpose of the organisation
- the operational context
- financial constraints and regulatory requirements
- the needs and expectations of the organisation and its stakeholders or actors

Essential aims are optimal adaptation and use of the interior rooms, ensuring the technical equipment's valuable and optimised function, the quality of the internal environment, information security, and other user needs (Pašek and Sojková, 2018). The asset owner is best suited to defining, articulating, and managing all these factors. The asset owner is also responsible for ensuring that all the necessary information can be appropriately managed in an AIM and adequately conveyed to actors when creating a PIM (Bilge and Yaman, 2021). This responsibility includes those contracted or subcontracted by the asset owner or appointing party to deliver in the handover process. Furthermore, the asset owner also has responsibility for safeguarding core activities that may include various services related to the tenant's or other users' needs. Examples are finance, use of areas, logistics, FM/AM, and public authority needs (laws, rules, duties for the building owner). Here, a strategic approach will support the realisation of benefits (Smith and Tardif, 2009).

To support the primary activities of the enterprise, the AM needs to have a bright, flexible, and value chain-based policy for the asset(s). This policy extends to the usability, safety and security of the comprised portfolio of assets and users.

Furthermore, all technologies must be managed and function nearly flawlessly at various operational levels and under agreed conditions. Finally, they must also be deployed as part of a business strategy to be successful (Smith and Tardif, 2009).

The enterprise BIM needs a transparent and holistic approach to exploiting the building information in general and in both foreseen or unforeseen trigger events (ISO, 2018c) to reap the benefits of ISO 19650. An effective AM requires information about the quality and quantity of resources for future planning and daily decisions.

The primary key to delivering the correct information is to define reliable information requirements that meet the defined purposes and enable efficient delivery throughout the project life-cycle (Bolpagni and Hooper, 2021). Such clarification means specifying what, when, how, for whom, and why the information should be produced. Therefore, the leaders of an enterprise must first articulate a clear strategic vision for using digital information (Smith and Tardif, 2009). Furthermore, they must contribute to a policy establishing the appropriate end-user roles' necessary information needs (LOIN) and defining the relevant processes and their workflow. In addition, they must ensure that the necessary standardised processes and information workflows are established with the appropriate parties, including a plan for utilising digital asset information. These processes are recommended to be supported by enterprise modelling techniques (Sandkuhl et al., 2014). In addition, several elements of the ISO 19650 standard can strengthen these processes and information management.

The business management should be especially aware of the width and depth of this standard's part 3 (ISO, 2020f). The contractual relationships in the operational phase can show a large spectrum, and the appointing party often has little influence on the delivery of information because of the trigger event. The reason may be that the delivery is driven by acquiring an asset owned by another organisation (e.g., purchasing or leasing equipment or an existing building). Furthermore, the ISO 19650 standard (ISO, 2018c) requires the appointing party to specify the information needed to maintain the health, safety, and security of the users/visitors of the asset, while referring to ISO 9001 (ISO, 2015b).

5.4 Project delivery or asset management perspective

The concepts and principles of ISO 19650 should be applied in a way that is proportionate and appropriate to the scale and complexity of the asset or project (ISO, 2018c). Furthermore, ISO 19650 outlines a clear responsibility for an appointing party (the client or someone managing information on behalf of the client) to understand and specify what project and whole-life asset-related information they require from the outset of the project onwards.

ISO 19650 (ISO, 2018c) further points out the importance of organising the collaboration between the participants involved in construction projects to achieve the desired delivery quality of the AIM into the operational phase. At the same time, it requires understanding the importance of a deep level of standardised processes to ensure clear communications, re-use, and an efficient sharing of information to reduce the risk of loss, contradiction, or misinterpretation (ISO, 2018c). Well-developed concepts and principles related to the project information requirements (PIR) will strengthen the delivery of agreed quality in the models. Through collaboration between the participants involved in construction projects and real estate AM, these new business models will significantly contribute to exploiting the technological potential to transform the business to the Enterprise BIM level of maturity. Such collaboration and standardised processes and concepts need customised CDE solutions, usually organised by the appointing party. Still, the leading appointed party in Norway is often the executing party. The unified purpose-driven information requirements should specify or guide how the project deliveries can be achieved. Therefore, the appointing party should ensure that these requirements are agreed upon in sufficient time to be delivered efficiently (ISO, 2018c).

The specific requirements for information management during the delivery of built assets are provided in ISO 19650-2 (ISO, 2018d). Furthermore, ISO 19650-3 (ISO, 2020f) should mainly be used for deliveries in the operational phase. However, several trigger events in the operational phase can also result in ISO 19650-2 being used.

Furthermore, in ISO 19650, the BIM execution plan (BEP) (ISO, 2018d) is a crucial process for obtaining the desired information deliveries in the delivery phase, generated by either PIR (delivery phase) or AIR (operational phase) (cf. subsection A). BEP explains how the delivery groups will carry out the project's information-related and administrative tasks. Thus, BEP defines processes identifying the BIM's goals and the BIM used for creating information models that correspond to the customer's information requirements. At the same time, the information exchange and definition of supporting infrastructure for BIM implementation are developed.

During the asset value chain, many possible trigger events, both foreseen and unforeseen, require different types of information for the individual end-users (Godager and Mohn, 2022). For example, in a planned or unplanned trigger event, the asset or its status changes, leading to the need for new or updated information for the appointing party (asset owner/operator) (ISO, 2018c). Therefore, the trigger events are mainly linked to part 3 of the standard (ISO, 2020f), and most active roles are linked to end-users.

The information management process in the operational phase can have significant variations in the information deliveries, depending on whether procurement and mobilisation can be planned for foreseen or unforeseen trigger events. Such planning is complex in the latter.

The information management process in the operational phase can have significant variations in the information deliveries, e.g., depending on whether procurement and mobilisation can be planned for foreseen or unforeseen trigger events. Such planning is complex in the latter. ISO 19650 Part 2 (ISO, 2018d) must also be used for major triggering events in the operational phase, e.g., unplanned trigger events and end-of-life processes. Where triggering events are predictable, the information handling process and requirements for information on assets can be predefined and prepared (e.g., annual maintenance tasks and repairs), and the appointed parties can be agreed upon in advance of necessary work. However, in unforeseen trigger events, the appointing party must initiate a process to establish the appropriately appointed parties, but preparing for these has significant benefits (Godager and Mohn, 2022).

5.5 End-user perspective

In the AECOO industry, the term "user" typically refers to persons, groups, or organisations using property or land as occupiers, owners, investors, insurers, tenants, visitors, or other actors. For example, members of the public might be users of campuses, hospitals, shops, amusement facilities, and libraries. The type of user will depend on the "use classes" of a building, i.e., what the area of use is. By using the term "end-user", we emphasise that we relate to the operational use phase. The end-users of buildings are very different, having different information needs. For this reason, all relevant user groups should be well represented when developing designs for new buildings or making changes to existing buildings. ISO 19650 has the framework to manage the need for information for the various roles or functions in the planning process.

Enterprise BIM seeks to offer comprehensive tools for digital building information that broader groups of end-users can use. An emerging desire of these end-users is the seamless user experience of customising the desired building information. The different information needs of these end-users can be divided into two groups: hard service ("space and infrastructure") and "soft service" (people and organisation) (Pašek and Sojková, 2018). One critical need is to identify and understand the actual requirements of these users and the purposes for which they need the information (ISO, 2018c), ISO, 2020f). These user requirements must therefore be identified and included in OIR, PIR, and AIR. These requirements will be more sustainable using the LOIN principles of ISO 19650. It is then vital that processes are carried out to identify which role needs adapted information so that this is considered in the requirements. By adopting a whole asset value chain approach, the end-users will likely get the most benefits from BIM (Project, 2016). Unfortunately, today's ICT systems do not provide the end-user with the central space needed to become an effective tool.

5.6 System model perspective

The system model perspective typically consists of the logical design of the information system and its characteristics, such as information, function, and network. It translates the content of the perspectives above into detailed specifications and corresponds to a systems model run/devised by a systems analyst.
ISO 19650 specifies a high-level architecture for a CDE, where information management is realised in BIM projects (ISO, 2018c).
Three core statements in ISO 19650 mark the cornerstones of this architecture (ISO, 2018c):

1. A common data environment (CDE) is a concept or an ecosystem for a given project or structure where CDE workflows and CDE solutions operate under agreed conditions.
2. CDE workflows for the production and handling of information must be implemented according to agreed rules, and information supply chains and exchange principles between CDE solutions are prepared.
3. CDE solutions can implement the activities and deliveries in CDE workflows, e.g., to produce, check, store, use, and share information (approved files, documents, and data/information for interdisciplinary teams in a managed process).

ISO 19650 does not focus on open formats to achieve interoperability, but this is recommended as a requirement. Using a structured CDE that allows the automation of processes is a crucial principle in ISO 19650. Enterprise BIM needs one or more well-functioning CDEs that can include various custom CDE solutions to support different defined activities and needs. Examples are construction projects and management related to the enterprise's core activities, both operationally and strategically. The CDE principles in ISO 19650-1 (ISO, 2018c) support the necessary architectural design of a CDE ecosystem, which facilitates CDE workflow and the collaborative production of documentation, management, sharing, and exchange of all information.

The CDE workflow can support the collaborative production of documentation, management, sharing, and exchange of all information. Furthermore, this CDE concept is fundamental to achieving high-level interaction, information sharing, and communication between all actors and active roles. For more giant enterprises, it will be necessary to have many customised CDE solutions in a CDE ecosystem.

5.7 Technology perspective

The technology model perspective describes the architect's model translated into a builder's model. In practice, the technical component perspective for Enterprise BIM defines the necessary components of a comprehensive information system in a CDE ecosystem. The technical solutions must handle large amounts of data and information and assess quality, access, and information security. In addition, it is vital to establish functional ICT architecture with search engines to generate reports based on subject-oriented searches (end-user operation).

5.8 The detailed perspective

The detailed perspective of an Enterprise BIM solution consists of implementing the various business components in a comprehensive information system for managing the necessary digital processes. Using the construction metaphor, Zachman refers to it as a subcontractor's perspective (Zachman, 1999), which makes sense to software developers when the design is implemented with modules or components acquired from the perspectives of the other. Elements of this perspective are typically programming based on the complete system model, implementation of information systems, and preparation of user documentation.

The contribution of ISO 19650 can here be linked to the implementation of CDE workflow, PIM, AIM, and information management in CDE solutions. Furthermore, this includes perspective configurations of processes, distribution, responsibility, and timing aligned with the perspectives above.

There are still challenges when exchanging information between CDE solutions, but the results from an ongoing CDE standardisation work in CEN are expected to be helpful. Such bridging is necessary for Enterprise BIM because the different roles require different CDE solutions and interoperability for jointly required information.

More and more information sharing will occur on dedicated cell phones or tablet solutions, which means that many actors can use the information on many platforms. As a result, there will be fertile ground for more adapted digital twins for the various applications within the Enterprise BIM concept. The operational digital twins will be put together by several databases, each with high-security requirements and a 100 per cent audit. Only in this way can one ensure that the information does not reach undesirable addresses. When assets are used, one must be aware of and consider that safety and security are linked to assets, equipment and people.

5.9 Enterprise perspective

The perspectives and elements highlighted in this section can be gathered and considered from a holistic Enterprise BIM perspective (functional enterprise). The CDE concept of ISO 19650 is fundamental to achieving such high-level interaction and sharing of data and information between all actors and active roles.

OIRs are the foundation for other requirements and will envelop the entire business. Therefore, a well-developed AIR will be of great importance to ensure that the information in AIM suits the various purposes of the operational phase. For this reason, it is a mantra in ISO 19650 that requirements must be purpose-driven.

There will be fertile ground for more adapted digital twins for the various applications within the Enterprise BIM concept. Throughout the life-cycle of organisations, there is typically a high turnover of providers of multiple services and individuals who must fulfil specific roles. However, the information management function, the ISO 19650 standard, and the processes will mainly be constant and support the migration and development of the information models across the enterprise's life-cycle.

5.10 Summary of the contributions of ISO 19650

Based on the Zachman framework's basic guidelines for purpose and content (Zachman, 2008), our comprehensive framework (Fig. 7) puts together the main essence by reviewing the different perspectives in Section 5. The main elements from the various perspectives are further specified below to support an understanding of the figures' perspectives.

In Section 5, the findings concerning the contribution of ISO 19650 to supporting the Enterprise BIM concept were grouped according to the perspectives of our expanded Zachman framework (Fig. 5). To arrive at a comprehensive overview of the different perspectives (views) and to be able to bring out the enterprise perspective, the next step has been to gather these main findings into this framework (Fig. 7). Zachman's original framework aims to provide an abstract representation, description, and definition of an identifiable business's structure, processes, information, and resources (Sandkuhl et al., 2014). Through such processes, the contributions to the organisation can be more easily understood, and its performance can be improved through the creation and analysis of business models (Godager et al., 2021). However, our study does not include such a holistic focus but limits itself to examining and summarising the potential of ISO 19650.

Based on the Zachman framework's basic guidelines for purpose and content (Zachman, 2008), our customised Zachman-based framework (Fig. 7) puts together the main essence by reviewing the different perspectives in this section. To further support the understanding of these perspectives, their main elements are specified below:

- The scope perspective (A) is crucial in clarifying and bringing about the organisational interaction between the strategic goals of the enterprise, the purpose-driven information needs (LOIN) for the various operational roles, the associated information requirements and processes, the workflow, and management of the necessary capability and capacity. A well-designed and functioning CDE ecosystem that facilitates communication and information sharing is essential to make this happen.
- The society's perspective (B) covers government requirements, laws, human rights, and regulations that all businesses must comply with. ISO 19650 recommends connecting these requirements to the OIRs. Handling society's perspectives should therefore be a sub-requirement for a CDE solution.

- The business management perspective (C) must ensure that the enterprise's motivation and scope perspective is realised. Herein lies the responsibility for the various information requirements (OIR, AIR, and PIR) for the business units to be satisfactorily coordinated and completed. An overview of processes and organisational matrixes are essential elements to achieve this.
- The project delivery and asset management perspective (D) must focus on a transparent delivery process that follows all the requirements. The main deliveries are PIMs and AIMs, but partial deliveries are related to establishing a master delivery plan (MIDP), BEP, and associated information transactions of information containers at different stages and states of sub-processes. The appointing party must ensure that the necessary CDE solutions are established in projects. Furthermore, the appointed party(s) must build their organisation to match the appointing party's needs and show sufficient capacity and capability according to ISO 19650. Only when AIM is established in an adapted CDE ecosystem will AM be capable of further development to fully use in an asset management system (cf. ISO 55000 series and ISO 19650 parts 1 and 3).
- The end-user perspective (E) has a prominent focus in this paper because of its vital position in achieving sustainable and helpful exploitation of the AIM. An essential part of sustainability is that the solution is profitable for all end-users, which means easy and fast access. Furthermore, the end-users need flexible and satisfying CDE solutions giving them easy access to information from AIM at both foreseen and unforeseen trigger events (Godager and Mohn, 2022). Such use assumes that the different roles and functions are satisfactorily involved in establishing the LOIN-based information requirements.
- The system model perspective (F) presupposes the use of a CDE ecosystem and covers the elements of the logical information model in corporate architecture. Furthermore, it includes describing and compiling business processes (based on business rules), responsibility, security, system rules, and technical information flow.
- The technological perspective (G) defines the physical components and their relationship to the entities of the Enterprise BIM system (inventory configuration). These definitions entail configuring data and information flow on CDE solutions and between different CDE solutions in a CDE ecosystem. The uniform solution must use newer and more flexible ICT technologies, making the information easily searchable and accessible (e.g. semantic web technology to define and connect valuable data/information within the enterprise) (Godager et al., 2021). At the same time, an implementation must be aligned with the strategies, rules, and guidelines from the perspectives in the matrix. Here access control and data and information security should also be included.
- The detailed perspective (H) ensures the contextual design and implementation of the physical data model. This way, available and standardised data and information can flow through various steps. In addition, the procedures described in ISO 19650 can contribute to facilitating the technical processes. The developed applications implement the newer ICT technologies, with a strong focus on adopting an interoperable and secure access-control system in the CDE solutions.
- The enterprise perspective (I) shows the entire instantiated enterprise. Here, the other perspectives are integrated and offer users a comprehensive information system as a solution.

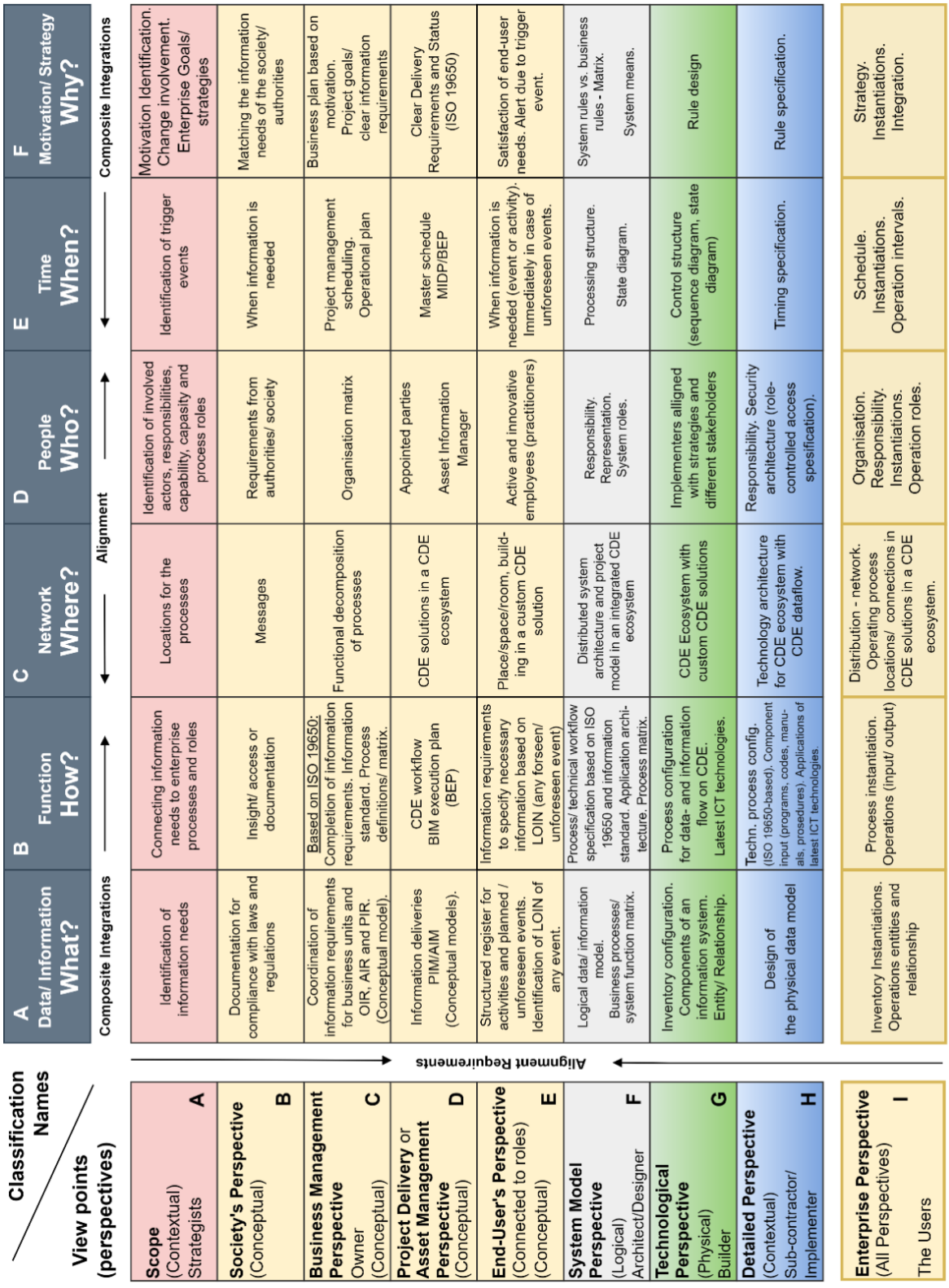

FIG. 7: Combination of contributions from ISO 19650 to the Enterprise BIM concept based on principles in the Zachman business ontology.

6. DISCUSSION

This section discusses how standards, mainly the ISO 19650 series, can help strengthen existing knowledge to support Enterprise BIM. The discussion primarily focuses on the results from reviewing ISO 19650 associated with the organisational link between AM and Enterprise BIM, although the more technical aspects related to, e.g., the use of CDE is also considered. Furthermore, findings exposing deficiencies or weaknesses in the first edition of the standard are discussed.

6.1 THE LOIN CONCEPT IN EN 17412-1 AND ISO 19650

This paper identifies the LOIN concept as crucial in helping meet the information needs of the various roles in Enterprise BIM. The associated information exchange described in ISO 19650 (ISO 2018c) can be supported by ISO 29481 (Information Delivery Manual) (ISO, 2016) and EN 17412-1 (LOIN) (CEN, 2020). Fig. 8 explains the main concepts related to information exchange based on EN 17412-1 and ISO 19650-1 and shows the connection to the application within Enterprise BIM, i.e., the digital information flow.

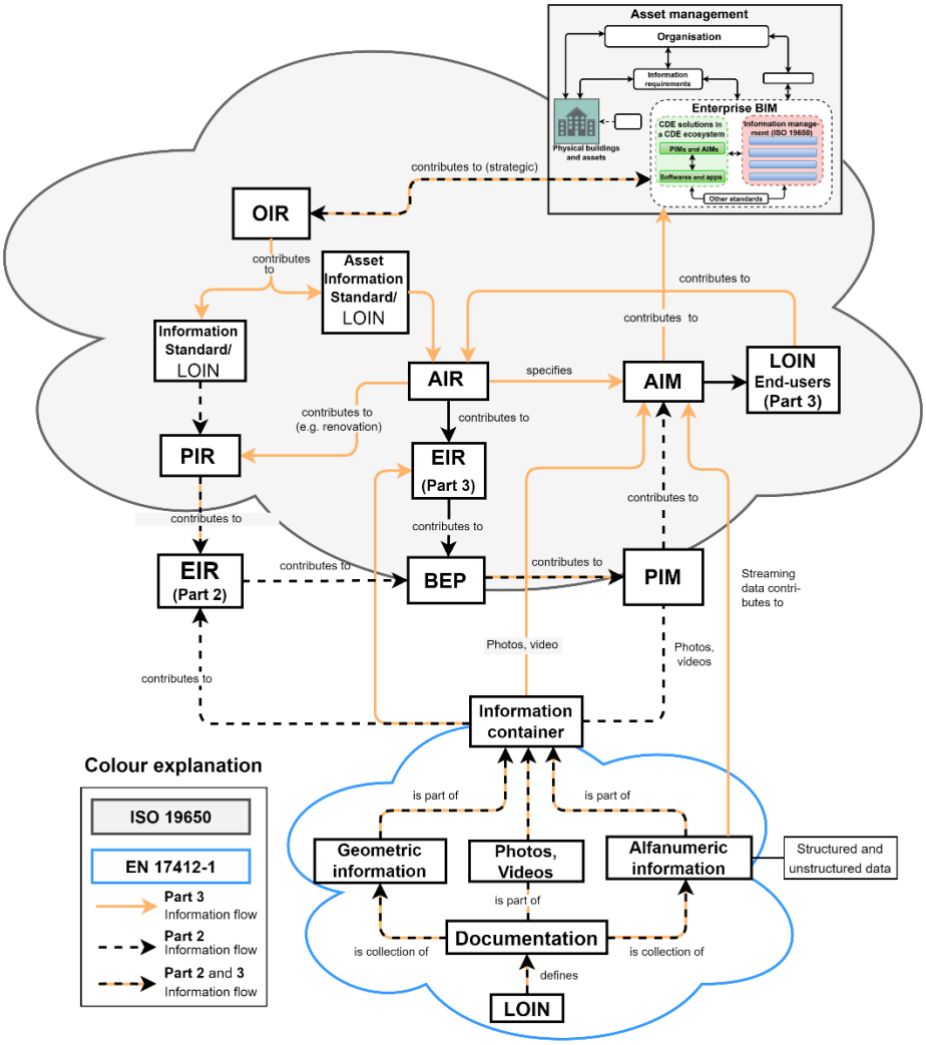

FIG. 8: Process map to show the main concepts related to information exchange included in EN 17412-1 and ISO 19650-1. The figure is a principal sketch inspired by Figure A1 in EN 17412-1 (CEN, 2020).

ISO 29481 is omitted from this figure to avoid undue complexity because the information delivery manual has yet to prove successful. In any case, the interactions and transactions are necessary to determine, and ISO 29481 is still being promoted. The EIR defines information exchanges and transactions that result in information

deliverables being exchanged in information containers (CEN, 2020), but EIR in a functional ICT context is underdeveloped and must be matured and tested in practice.

Fig. 8 shows the importance of a well-developed OIR as the basis for data and information flow, and this should be related to the goals and objectives of Enterprise BIM. The various information requirements (OIR, AIR, PIR, and EIR) must all be based on LOIN principles, i.e., only the information that is defined as necessary is required. EN 17412-1 and its future parts 2 and 3 will support the information flow and the guidelines for the delivery of the digital information. In the figure, the data flow for new projects based on ISO 19650 Part 2 (deliveries) has a dashed line, while the operational data flow (Part 3) has solid lines. The figure used a combination of solid lines (orange and black) and dashed lines where the information flow appears common to the delivery and operational phases. We envisage that the information flow from the information containers is mainly exchanged according to EIR (separate EIR for delivery and operational phase) and BEP. In the operational phase, the data flow can also go directly to PIM or AIM (e.g., continuous alphanumeric data flow that goes directly to AIM). Furthermore, AIM contributes to the development and updating of Enterprise BIM.

Overall, Fig. 8 emphasises that the data and information flow is very different in the delivery and operational phases and is significantly more nuanced in the latter. At the same time, there are fundamental differences in the approach to information management, primarily around whether procurement and mobilisation can be done ahead of the trigger event taking place or not (Godager and Mohn, 2022). This identifying observation indicates that the standardisation of the data and information flow in the operational phase should receive more detailed attention in future research and development to reach new levels of profitable digitalisation. Research and development (R&D) and the construction industry lack such a focus.

6.2 Assessment of the functionality of ISO 19650-based information management using CDE/CDE ecosystems

The ISO 19650 series seeks to implement standardised best practices for parties in the AECOO industry by providing a framework that facilitates the parties to agree in advance on the information and deliveries required by the appointing party (ISO, 2018c).

Overall, ISO 19650 emphasises the need for the appointing party to take responsibility for managing asset information management throughout the value chain of assets, thereby improving the opportunity to realise the potential benefits of utilising building information through all phases of assets and infrastructure portfolios. Furthermore, regulations will increasingly be anchored internationally. However, such a responsibility requires adaptation to the actual local conditions, regardless of the place in the life-cycle. The value chain of the assets involves huge and fluctuating groups of people who work together for limited periods and simultaneously have different technological knowledge (ANZGuide, 2019). Nevertheless, to achieve the value of ISO 19650, it must be ensured that everyone involved understands the general information management process through the asset's value chain and the significance of each actor in this process (ANZGuide, 2019). However, the ISO 19650 requirements are general and, by nature, not normative. Therefore, it is a great need to research and gradually develop and improve best practices. Based on experience and unmet and new needs, we think the standard will probably have to be revised quite early.

At the same time, the market demand for CDE workflows, CDE solutions and CDE ecosystems is increasing. From a "vertical" perspective, a CDE solution supports processing at both high- and low-level management levels, from both AM and the project level. Although the contributions from the CDE description in ISO 19650 are a good foundation, the market's available CDE solutions and communication between them still have obvious shortcomings and challenges (e.g., standardisation, flexibility, and efficiency). Furthermore, current CDE concepts and solutions are developed mainly at the level of electronic document management (Losev, 2020). Therefore, they greatly lack the prerequisites to be used as a basis for implementing a well-functioning and profitable Enterprise BIM solution (Godager et al., 2021). At the same time, federated CDE infrastructures must distinguish between ongoing work, shared and published information (cf. ISO 19650), including standardised use of metadata (Pauwels and McGlinn, 2022). Users need more national guidelines besides the CDE guidance from the UK BIM Framework. It is also necessary to explain how to implement such solutions and make them fit the actor's workflow and needs. Here, with its preliminary work, the German DIN initiative may support explanations of what a CDE is, how it can be implemented, and function sets and open data and information exchange between platforms of different vendors (DIN, 2019a, DIN, 2019b). In parallel and in addition to this Work Item Proposal for an "Open

Application Programming Interface (API)", standardisation on a "Framework and Guidance to CDE" is intended and was launched in parallel with CEN technical bodies TC 442. It covers the technical implementation aspects and its organisational introduction to the parties in the participating project.

6.3 Assessment of contract types considering information management in ISO 19650

The entry of ISO 19650 raises new challenges related to the legal and contractual consequences of digitalising information management. Many of today's projects are carried out with contract forms (at least in Norway) that prevent the potential of the ISO 19650 series from being fully utilised. In Norway, we have strong silos, and it may seem that today's industry does not want the needed changes (Lohne and Mohn, 2022). The same conservatism applies to barriers to the traceability of products used in assets (Mohn and Lohne, 2022). Therefore, it is only possible to reap the full benefits of technological innovation with parallel innovations in processes and policies related to the legal and contractual consequences of digital information management (Winfield, 2020). Furthermore, ISO 19650 stimulates a holistic mindset with its value chain and life cycle-focused framework, but this is new for the AECOO industry and crucial when the sustainability dimensions are to be taken care of.

As a consequence, new contract types must be developed to meet the requirements required by ISO 19650 and the UN's sustainability goals. The framework does not describe how the technologies can be utilised or how the necessary innovation is to be done. However, it can prevent ad hoc solutions through purpose-driven management and standardised processes. At the same time, it is a challenge for the contracts that the transition from analogue to digital processes occurs at different maturities within different parts of the AECOO industry (Alaloul et al., 2020). This will quickly lead to practical, processual and logistical problems (e.g., coordination and interoperability), legal and contractual complications and ambiguity (Winfield, 2020). In any case, the questions of legality and contracts cannot be ignored or taken for granted until ambiguity and dispute arise due to differing perceptions of legality and contract (Winfield, 2016). At the same time, social interaction (Turner, 1988) and risk management must be taken care of by new contract regimes that serve the entire value chain.

Furthermore, trust and information sharing must be developed between all partners to succeed. In contracts, risk can be managed, minimised, shared, transferred or accepted, but it cannot be ignored (Latham 1994). The contract agreements must, therefore, also be developed and adapted to ISO 19650. Here, researchers have also introduced concepts for blockchain integration and smart contracts to support the flow of information in various CDEs (Ciotta et al., 2021). For Norway, the problems will be linked to the existing silos, which have created substantial barriers and prevented transparency and trust between the various actors. Moreover, a regime for applying risk management throughout the value chain is poorly developed. These challenges must be tackled and will require R&D for the entire industry.

6.4 Assessment of findings to meet the needs of Enterprise BIM

To develop the Enterprise BIM concept, ISO 19650 is identified as the mainstay of connecting existing and future standards for possible automation and streamlining the interdisciplinary interaction of asset information throughout the value chain. Therefore, the ISO 19650 standard can be seen as the rulebook, setting out the recommended concepts and principles for business processes across the construction industry to support the collaborative and purpose-driven production and management of digital information during the value chain of assets.

Due to the AECOO industry's low level of digitisation, the first version of ISO 19650 mainly focused on meeting today's needs at maturity stage 2 (ISO, 2018c). At the same time, a fully developed Enterprise BIM solution operates at maturity stage 3 (Godager et al., 2021). Nevertheless, this review shows that it found much value in developing Enterprise BIM. The compilation in our expanded Zachman framework (FIG. 7) offers many contributions from different perspectives (viewpoints). In this research, the ISO 19650 framework supports Enterprise BIM, such as managing information requirements based on the LOIN principles and the basic principles of CDE establishment and management (ISO, 2018c). This review provides a conceptual overview, and the practical follow-up and the detailing related to the implementation and use of ISO 19650 must be carried out by real business actors.

The built environment is becoming increasingly sophisticated, complex, and demanding, and it involves increasing automation and intelligent technologies. At the same time, this paper shows the importance of the enterprise business knowing what information its various end-users need to perform their roles. Here, only the necessary information should be required in projects and adapted information systems. To reach that level, however, a

cultural change is needed. Transparent management will ensure end-user involvement in the information requirements process. Such control ensures that the information needs of the various end-user roles are taken care of.

ISO 19650 Part 3 offers a framework to handle both foreseeable and unforeseeable trigger events. Especially in a crisis, it is decisive quickly obtain the necessary asset information for the various roles involved. As such, it means that the businesses can use the framework in ISO 19650 to develop a policy for crisis planning for particularly critical scenarios (e.g., as requirements to assets in OIR). Furthermore, ISO 19650 with Enterprise BIM as an information provider can help to support necessary asset documentation to safeguard the UN's sustainability goals.

In the operational phase, both the owner's and customers' expectations of products and services in Enterprise BIM will constantly be evolving. Increased utilisation of IoT and sensors will also influence and make the use of assets more efficient by Big Data simulations optimising the needs and thus the use and management of assets. Furthermore, users/customers expect practical and valuable information services to be easily accessible on mobile solutions and seamless interactions within the business across channels. Facilitating such wishes and needs depends on utilising the available technologies and their connection to necessary processes and those performing the many and varied roles required. Nevertheless, by setting reasonable information requirements, the UN's sustainability goals (3 good health and well-being, 8 decent work and economic growth, 9 industry, innovation, and infrastructure, 11 sustainable cities and communities, 12 responsible consumption and production, 13 climate action) (United Nations, 2015) can be safe-guided at the same time. Here, to react, the appointing party must be able to track direct and indirect emissions in the value chain, i.e., at all stages of the process, from the raw materials to the finished product.

A digital transformation of an enterprise or organisation into a developed Enterprise BIM concept provides significant innovation and competitive advantage opportunities. At the same time, it will require a complete rethink of the organisation's cultural, strategic, technological, and operational needs for changes. Development of the Enterprise BIM concept can not only be pushed by the supply chain, but intelligent client capacity also recognises the benefit of looking at the whole life value of combining the use of BIM more strongly with AM. From this perspective, it is not only the delivery phase that can benefit from BIM. Everyone involved throughout the entire value chain of the built environment will do so. The ISO 19650 series clearly shows the potential to support this information management needs in a business through its framework for organising building information. However, a holistic strategy linking OIR, the other information requirements (AIR, PIR, EIR), and information standards can support the necessary changes.

Using ISO 19650, OIR can be linked to the strategy and other information requirements (AIR, PIR, EIR) and information standards. Nevertheless, OIR could be better developed in most enterprises in the AECOO industry today. OIR must be included in the new business plans which describe the digital world. There it must have its sections, which indicate the interaction between information in the asset (Enterprise BIM) and the physical asset, as shown in FIG. 4. This will also help to strengthen this standardisation of processes and will also be able to promote the utilisation of possible efficiency technologies. Thus, the potential benefits of implementing ISO 19650 should not be underestimated (ANZGuide, 2019).

The standard is only a basic framework, not a recipe to be directly implemented and utilised in an enterprise or a project. Therefore, solid efforts are needed to understand the picture of opportunities it provides and its support from developing best practices for the application. In this process, national guidelines need to support the implementation of the standard. ISO 19650 has the hooks, but the framework needs supplementary content, i.e., practical implementation, to develop requirements for the ICT solutions for end-users in the next round. In addition, it is also crucial that the local cultures are taken care of. So far, only the United Kingdom has created its own National Annex (Winfield, 2020). Adapted nation-wise guides will be able to draw much valuable inspiration from these UK guides.

At the same time, the Enterprise BIM concept needs to be able to share updated information in a user-friendly and efficient way. Semantic web technologies are likely part of the solution to enable custom digital twins (Sacks et al., 2018, Dinis et al., 2021). Including the use of ISO 19650, Pauwels and McGlinn (2022) show how different data models and web technologies can be created and used for the built environment within the AECOO domain using ICT techniques such as JavaScript Object Notation (JSON) to Extensible Markup Language (XML) and

EXPRESS to Resource Description Framework (RDF)/Web Ontology Language (OWL), for modelling geometry, products, properties, sensors and energy data.

Standardisation work (CEN) and research projects within digital twins are also ongoing. It is crucial that the purposes of digital twins are concrete and are linked to simulations of applications of both existing assets and possible future scenarios in the operation of assets. A full-scale implementation of ISO 19650 is currently demanding, but the implementation guidance work started and led by CEN will hopefully help.

7. CONCLUSION

This paper's primary purpose has been to comprehensively analyse how the current ISO 19650 series can support information and business management of Enterprise BIM. The focus has been on improving the information management practice for the value chain of built assets. ISO 19650 Part 3's forward-looking framework for handling the operational phase has been essential for evaluating the standard's potential to support better integration between Enterprise BIM and AM. In addition, adjacent standards are analysed.

Enterprise BIM seeks to establish a comprehensive organisational life-cycle concept, which allows an expanded number of relevant actors to use the building information through a common data environment (CDE) ecosystem. Previous research has demonstrated the importance of a standardised information structure throughout the whole life-cycle of the built environment as a critical element in achieving the information-rich Enterprise BIM vision. Although ISO 19650 is mainly aimed at supporting information management related to BIM maturity stage 2, this review shows significant contributions even though Enterprise BIM operates at maturity stage 3.

Our study shows that the ISO 19650 series significantly contribute to the industry as a whole and the development of Enterprise BIM. Some of the most important contributions are analysing the possibilities regarding how an enterprise can utilise the standard. Examples here are the development of information requirements (OIR, AIR, PIR and EIR), the information models (PIM and AIM), and the concepts of "level of information needs" (LOIN) and CDE. The paper shows how these can be put into a holistic life-cycle context to support asset management and strengthen the Enterprise BIM concept. ISO 19650-3 (the operational phase) is identified explicitly as rich in content and valuable in supporting the development of Enterprise BIM by having an enterprise focus and managing portfolios of buildings and infrastructures. At the same time, our review shows that the primary key to establishing holistic information management in the operational stage within the Enterprise BIM structure is the development and establishment of a solid and transparent OIR based on comprehensive strategies and goals for the business.

An extended Zachman frame matrix has been developed to collate the findings and visualise the results from different perspectives and contexts. As with ISO 19650, the traditional business management perspective is further subdivided by adding society (1), project delivery or asset management (2), and the crucial end-user perspective (3).

Furthermore, this paper finds some parts of this first standard version general and has identified a need for an appropriate implementation guide. At the same time, Enterprise BIM also needs to see ISO 19650 in the context of standardisation connected with the establishment and information management related to IoT and sensors in digital twins.

The intention of the standard is not to be a simple recipe. Instead, it is a basis for the operationalisation of information management in the enterprise, organisation or project. Therefore, using the standard needs supplements from best practices for the application. Only the UK BIM Framework has so far done extensive work in this area.

Reviewing the potential for utilising ISO 19650 provides valuable insights for enterprises that manage building information and the AECOO industry. It will help facilitate the entire industry's understanding of the power of this game-changing standard and inspire it to participate in the vital work of developing best practices for information management. Furthermore, this study provides these target groups with an available resource to acquire an overview of the possible contributions of ISO 19650. As such, this study highlights the necessity and scope of opportunity in holistic standardisation and the development required to further the diversity of research within the standardisation area to achieve a more coordinated and purpose-driven building information management.

Naturally, this article is conceptual in nature which could be viewed as a limitation, and the proposed concepts need further development in an empirical setting. Moreover, another limitation is that the Enterprise BIM framework modifications must also include topic areas such as information security, exchange, and management. For instance, not including information security opens enterprises up for cyber-attacks and espionage, especially for large public sector organisations. Further, semantic web technologies lay beyond the scope of ISO 19650. Follow-up work is needed because further research related to the organisation and use of CDE in the use phase is necessary. It is necessary to test and evaluate LOIN in interaction with OIR, AIR, PIR and EIR in customised enterprise CDE solutions to determine the information needed (Fig. 1) and practical application for different end-users in real projects or assets. Furthermore, there is a need for research with a stronger emphasis on OIR's power and potential as a management tool for further Enterprise BIM development. A need has also been identified for further research that combines the concepts in ISO 19650 with the possibilities within semantic web technologies. At the same time, the focus must also be on achieving simple opportunities to obtain the necessary building information to respond to the UN's sustainability goals. Despite its broad scope, this paper has only briefly mentioned some of the essential standardisation contributions of the ISO 19650 series. Hopefully, actors in applied and unapplied research areas will be encouraged to explore other elements related to the standard.

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