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Implementing asset information requirement templates for corporate real estate management: A study in the chemical industry

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ABSTRACT

Research on building information modelling (BIM) for corporate real estate management (CREM) in the chemical industry remains limited. This is largely due to a lack of documents supporting BIM adoption and implementation. The present study identifies, compares, and applies different approaches to the definition of asset information requirements (AIR) templates for facility services in the chemical industry. It subsequently translates the results into recommendations for AIR template implementation and formalises them into implementation steps. The results indicate that process diagrams are an expedient approach to the definition of AIR templates. Recommendations for their implementation concern information management software, static data prioritisation, accuracy limitations, asset types and sub-types, and stakeholder involvement. The present study contributes to the body of knowledge by identifying an expedient approach to the definition of AIR templates, providing AIR for four BIM Uses, and proposing an AIR template implementation framework for CREM in the chemical industry.

1. Introduction

The construction industry sector has considerably intensified its digitisation effort over the past few years. Still, it lags behind many other industry sectors and a multitude of processes remain analogue or only partially digitised (European Construction Sector Observatory, 2021; Daniotti et al., 2020). Building information modelling (BIM) plays a pivotal role in the digitisation of this industry sector, as it constitutes the core element of numerous promising technologies (EU BIM Task Group, 2018). BIM adoption, that is, acceptance, can be observed in more and more design offices, building contractors, and client organisations whereas BIM implementation, that is, its practical application, increases primarily in the design and construction phases (Saka and Chan, 2021). Hence, BIM implementation in the operational phase is rare, despite the considerable financial benefits it is expected to yield for owners and operators (Gerbert et al., 2016; Wyman, 2018). Relevant studies estimate the financial impact of the operational phase between 60% (Lewis et al., 2010) and 85% (Scarponcini, 1996) of the accumulated life cycle cost. This applies even more in the chemical industry, as maintenance and technical building services often represent one of the biggest expenses in this industry sector (Chin et al., 2020; Sheward, 2021). Therefore, efficiency gains in facility service provision through BIM are highly attractive for corporate real estate management (CREM) in the chemical industry, that is, the management of buildings directly related to an organisation's core business (Glatte, 2021; Heywood and Kenley, 2013). Still, research on BIM implementation in CREM is under-represented "despite [the] disproportionate physical dominance [of corporate real estate] within most societies" (Abideen et al., 2022). BIM implementation demands specific asset information requirements (AIR) setting out the information that must be provided to efficiently support the execution of asset-related processes, for instance, the inspection of technical building services. As clients, owners, and operators often struggle with the definition of comprehensive yet concise information requirements, the definition of CREM-specific AIR poses a significant obstacle to BIM implementation in this context. Various relevant studies suggested further research on AIR templates (Cavka et al., 2017; Dixit et al., 2019; Munir et al., 2020) and guides on AIR implementation (Alshorafa and Ergen, 2020; Ashworth et al., 2017; Mayo and Issa, 2016). In this context, associations like (Deutsches Institut für Normung e.V., 2021), (buildingSMART International, 2023) or (BIMe initiative, 2023) propose different approaches to the generalisation of information requirements. At the same time, relevant research also indicates that generalisations of information requirements across all industry sectors may be of limited accuracy, as an organisation's industry sector strongly influences its information requirements (Cavka et al., 2017; Munir et al., 2020). As the chemical industry depends on highly specialised and

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engineered buildings, the operational phase in this industry sector often relies on well-defined and highly specific information to fulfil hygiene-, safety-, and maintenance-related requirements (Seuring, 2003; Teufelhart, 2013). Approaches to the definition of AIR templates in this context need to meticulously consider these characteristics.

2. Literature review

The following subsections elaborate on the current state of research on the topics "AIR for facility services", "Approaches to the generalisation of information requirements", and "CREM in the chemical industry" to identify research gaps and derive corresponding research questions.

2.1. AIR for facility services

ISO 41011 defines facility services as a "support provision to the primary activities of an organisation, delivered by an internal or external provider." (International Organisation for Standardisation, 2017) On a European level, EN 15221–4 provides descriptions and classifications of facility services, including the activities, facilities, and processes necessary for their provision (Comité Européen de Normalisation, 2011). The BIM-based information delivery for a facility service can be structured by defining a corresponding BIM Use and its AIR. (buildingSMART Alliance, 2013) defines a BIM Use as "a method or strategy of applying Building Information Modelling during a facility's lifecycle to achieve one or more specific objectives." ISO 19650-1 specifies that the "AIR set out managerial, commercial and technical aspects of producing asset information" to answer the asset-related organisational information requirements (OIR). (International Organisation for Standardisation, 2018) To implement a BIM Use, clients, owners, and operators need to define BIM Use-specific information requirements and include them in the AIR, which are then encapsulated in the exchange information requirements (EIR). The project information model (PIM) is populated with the requested information during the design and construction phases. After completion of the construction phase, the PIM is converted into an asset information model (AIM) and handed over to the clients, owners, and operators. ISO 19650–3 further specifies this progression of information requirements in the context of the operational phase, as shown in Fig. 1.

Fig. 1 depicts how the CREM department of an organisation, acting as the operator of an asset, defines information requirements for the operational phase. This sequence illustrates that the AIR play a pivotal role in the model-based information delivery for a BIM Use and the underlying facility service, as they are crucial to the provision of complete and accurate deliverables. As shown in Fig. 2, the BIM workflow concentrates more work effort in early project phases than the traditional workflow, calling for early agreements on BIM deliverables and delivery times. Accordingly, clients, owners, and operators need to assert BIM Uses for the operational phase and the necessary AIR early on (Messner et al., 2019).

However, a lack of pre-defined AIR for facility services impedes early AIR definition and implementation. The following studies investigated the definition of AIR for facility services:

(Mayo and Issa, 2016) identified a lack of guides on information structure and content for owners and operators. As a result, the authors suggested further research on the precise definition and implementation of AIR templates for clients, owners, and operators (Ashworth et al., 2017). identified a lack of research on customised information requirements for facility management (FM) that can be used autonomously by FM professionals. The study defined and tested an EIR template and a guiding document on its implementation. The results showed that the FM industry needs unambiguous templates and guides to promote BIM implementation. The authors suggested further research on contractually issued and predefined information requirements (Cavka et al., 2017). pointed out that owners struggle with insufficient knowledge and experience regarding the information requirements for FM as well as difficulties in information acquisition for BIM. The study investigated the definition of process information requirements to support the life cycle management of assets. The results showed that process information requirements can be derived from codes, design standards, organisation information requirements, project information requirements, and personnel information requirements. It also showed that generalised information requirements for all industry sectors may be inaccurate, as an organisation's industry sector strongly influences its information requirements for the operational phase (Dixit et al., 2019). identified a lack of research on challenges impeding the integration of BIM and FM. The study identified a total of 16 key issues in four categories. The authors concluded that the main reason for the erroneous delivery of information was a lack of explanative documents. The authors suggested further research on the development of documents supporting the definition of BIM Uses and information requirements (Munir et al., 2020). pointed out that FM professionals often struggle to articulate precise information requirements, impeding BIM implementation in this context. The study investigated mandatory key information requirements for BIM-based asset management. The results showed that every aspect of the operational information requirements needs to be specified in alignment with an organisation's asset management and business strategies to create business value through BIM. It

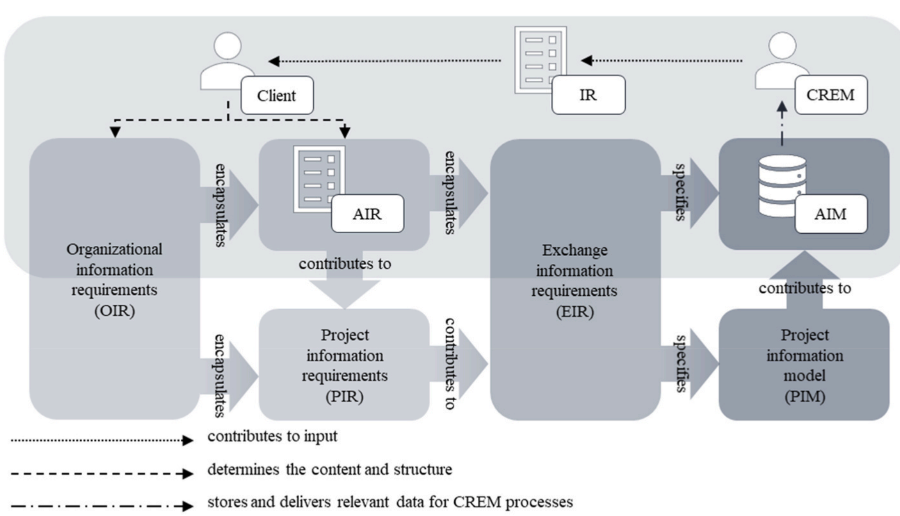

Fig. 1. Progression of information requirements based on ISO 19650–3, illustrating the flow of information requirements (IR) from CREM to the client to be included in the AIR and, ultimately, handed over in the AIM.

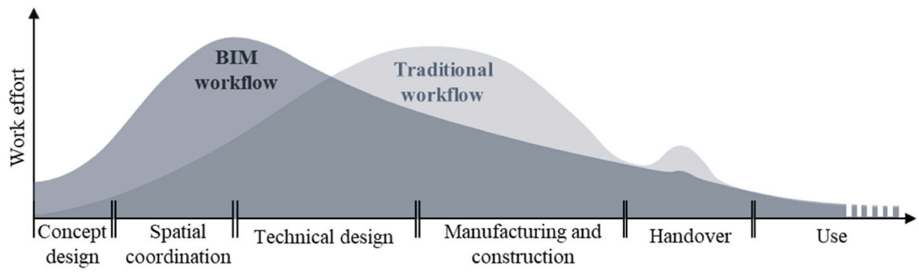

Fig. 2. Effort distribution over the life cycle phases in the traditional workflow compared to the BIM workflow.

also showed that the industry sector of an organisation influences the type and nature of its information requirements for BIM-based processes. The authors suggested further research on information requirement templates to provide a base structure for asset owners with limited BIM experience (Alshorafa and Ergen, 2020). identified a lack of guides on the definition and implementation of BIM Uses. The study found that information requirements in existing standards are either very extensive or not inclusive. The authors suggested further research on the development of guides for specific BIM Uses to further promote BIM implementation.

Based on the relevant research by (Cavka et al., 2017; Dixit et al., 2019; Munir et al., 2020), the generalisation of information requirements to define AIR for BIM Uses in the operational phase constitutes a research gap impeding BIM implementation in this life cycle phase.

2.2. Approaches to the generalisation of information requirements

In its BIM standardisation roadmap from 2021, (Deutsches Institut für Normung e.V., 2021) advises the development of standards recommending the scope and content of BIM Uses. However, it explicitly excludes the standardisation of information requirements or implementation processes from this advice. At the same time, (buildingSMART International, 2023) initiated the Use Case Management (UCM) platform specifying operational processes and information exchange requirements based on the information delivery manual (IDM) methodology. It provides descriptions, processes, and information requirements for BIM Uses. The “Model Use Templates” by (BIMe initiative, 2023) are yet another project in this field. It aims to compile “all the activities, resources, and methods necessary to generate a Model Use.” These different approaches to the standardisation of BIM Uses indicate disagreement on how and to which extent BIM Uses and their information requirements should be generalised.

2.2.1. Triangulation-based approach

Relevant research frequently applies triangulation methods for the generalisation of information requirements. In most cases, triangulation methods describe the consideration of a research object from three or more perspectives, increasing the reliability of research results by including multiple investigators, theories, methods, or data sources (Flick, 2018). The following studies applied the triangulation-based approach:

(Mayo and Issa, 2016) aimed to provide a “standardised base list of deliverables” allowing owners and operators to define deliverables and information requirements autonomously. Therefore, a two-round Delphi survey was conducted. Information requirements were then identified based on the agreement between the two survey rounds (Alshorafa and Ergen, 2020). aimed to define information requirements and their level of development (LOD) for selected BIM Uses. Therefore, an expert panel was divided into three groups and information requirements were defined based on a triangulation between the responses (Uhm and Lee, 2021). defined information requirements for FM by comparing relevant information from FM documents with Construction Operations Building Information Exchange (COBie) data sheets. The authors applied a triangulation approach using three methods: job shadowing, expert interviews, and FM document analysis.

Data source triangulation is applied as the first approach to the generalisation of information requirements in the present study. It is worth noting that none of the relevant publications applied the triangulation-based approach in the context of the chemical industry. This limits the extent to which the information requirements defined in those publications can be applied in the present study.

2.2.2. Process-based approach

Alternatively, relevant research frequently adopts a process-based approach to the generalisation of information requirements. This approach is often applied in the context of clearly defined process sequences. The following studies applied the process-based approach:

(Tian and Jiang, 2017) aimed to analyse the semiotic aspects of BIM and the information requirements that need to be met for successful BIM implementation in FM. Therefore, the study investigated the information requirements for BIM-based FM service delivery. The authors then developed a “BIM-based facility service model” containing service processes and providing an up-to-date representation of the asset (Helmus et al., 2019). aimed to collect relevant FM information to facilitate the information exchange between BIM and CAFM software. Therefore, the authors initially defined process diagrams for FM activities in collaboration with partner companies from different industries. Relevant information requirements were subsequently derived from these process diagrams. The study was conducted with limited participation by CREM professionals, exempting their points of view from the results (Bartels, 2020). developed standard process diagrams for selected FM activities. Based on that, information requirements were defined and evaluated by FM professionals. The author then created BIM Use-specific property sets for FM-relevant inventory and process data (Demirdöğen et al., 2020). developed a process-based FM framework to support the implementation of lean management philosophies in healthcare facilities and to promote stable processes and workflows. The framework was developed based on two case studies and evaluated by an expert panel for further improvement.

Process-based information requirement definition is applied as the second approach to the generalisation of information requirements in the present study. However, the relevant publications lack BIM Use- and industry-specificity, weakening their applicability to the chemical industry. As the identified approaches to the generalisation of information requirements differ considerably, the present study aims to evaluate their expediency in the context of CREM in the chemical industry.

2.3. Corporate real estate management in the chemical industry

CREM describes the management, provision, and operation of corporate real estate, mostly including buildings for research and development (R&D), offices, storage, production, and retail purposes, according to the industry sector of an organisation (Krumm, 2001). However, the precise delimitation of what “corporate real estate” includes is inconsistent. The present study defines it as real estate exclusively held for purposes directly related to the core business of an organisation, that is, houses its business or productive activities, in organisations where the core business is not real estate (Core Net Global, 2022; Glatte, 2021; Heywood and Kenley, 2013). In the chemical industry, CREM encounters several unique challenges. It is often located upstream in supply chains, making it an essential part of numerous downstream industries and production steps. Sites are often extensive due to the complexity of production processes involving numerous different plants and stakeholders (Blackburn et al., 2015). The maintenance of technical installations and machines, technical building services, and facilities is of exceptional importance in this context, both from a production and safety perspective (Deloitte Development, 2017). Real estate in this industry sector often includes highly specialised and engineered buildings for R&D as well as the storage and production of chemical substances. Due to all these characteristics, the chemical industry is a multi-stakeholder environment including external service providers for maintenance and examinations as well as different owner-operator constellations. CREM departments in this industry sector often have well-defined and highly specific information requirements to fulfil hygiene-, safety-, and maintenance-related codes and regulations (Seuring, 2003; Teufelhart, 2013). However, the request and gathering of data in the chemical industry are impeded by competing interests, as the variety of stakeholders, non-disclosure in the field of R&D, and information requirements for CREM do not always harmonise (Little et al., 2023). The following studies investigated CREM in the chemical industry:

(Tong et al., 2019) identified a lack of research on the maintenance supplier valuation and selection processes in the chemical industry. The authors pointed out that this industry sector requires special attention to safety-related aspects. The authors suggested further research on customisable supplier valuation and selection criteria, as many of them may be organisation- and industry-specific (Agung and Siahaan, 2020). identified a lack of managerial commitment to the implementation of total productive maintenance approaches in chemical companies. The study investigated different approaches to enhance maintenance efficiency in that context. The results showed that planned maintenance and quality management are the most impactful maintenance aspects to achieve "overall equipment effectiveness". The authors suggested further research on digitised maintenance and processes in this context (Chin et al., 2020). identified a lack of research on maintenance strategies in the chemical industry. The study analysed recent developments in the field of asset management in this context by comparing different maintenance methods, as equipment and technical building services run under rigorous conditions, requiring constant maintenance and risk assessments. The results showed that building maintenance can be one of the most significant parts of the operational budget in the chemical industry. The authors suggested further research on the creation of digital twins coupled with big data analytics for the chemical industry (Sheward, 2021). identified a lack of collaboration between designers and operators during the design stages of laboratory buildings, leading to suboptimal design decisions regarding heating, ventilation, and air conditioning (HVAC). The author pointed out that HVAC building services are critical for the trouble-free operation of laboratories, as they often determine the security of occupants. Additionally, they can account for up to 50% of an asset's energy consumption due to constant operation. The results showed that the early consideration of the operational phase promises considerable improvements in the planning process (Braun et al., 2022). identified a lack of research on the evaluation of potential benefits through preventive maintenance in the chemical industry. The study investigated the technical and procedural aspects of vendor evaluations for predictive maintenance to develop a "predictive maintenance analytics model". The results showed that the developed model was successful, but that any generalised model requires individual customisation before application.

Given the unique characteristics and challenges in the chemical industry, specific AIR templates and implementation guides are essential, as other industry sectors are expected to emphasise other asset types and facility services. Furthermore, CREM professionals in the chemical industry often deal with large amounts of sometimes highly heterogeneous data. Most CREM departments implemented ERP, CAFM, and CMMS software to streamline information management. Any user-centric approach to support CREM in the chemical industry has to adjust to the established ERP, CAFM, and CMMS software, as complex solutions and additional work are to be avoided (Leygonie et al., 2022).

Based on the results of (Abideen et al., 2022; Little et al., 2023; Seuring, 2003; Teufelhart, 2013), assets in the chemical industry define highly specific information requirements while several challenges impede information gathering and BIM implementation in this context. To address this research gap while considering the results of (Cavka et al., 2017; Munir et al., 2020), the scope of the present study was narrowed to the chemical industry.

2.4. Research questions

Based on the relevant research and the identified research gaps, the following research questions were defined:

RQ 1: Which approaches to the generalisation of information requirements for BIM Uses exist?

RQ 2: Which is the most expedient approach to the definition of AIR templates for CREM in the chemical industry?

RQ 3: Which recommendations are necessary to facilitate the implementation of AIR templates for CREM in the chemical industry?

RQ 4: Which steps are necessary to formalise the implementation of AIR templates for CREM in the chemical industry?

3. Methodology

As research on AIR templates for CREM in the chemical industry remains highly limited, the present study adopts an exploratory, mixed-methods approach. (Li and Zhang, 2022; Sarstedt and Mooi, 2019). Narrowing the focus to the chemical industry addresses the two obstacles mentioned above: the link between an organisation's industry sector and its information requirements (Cavka et al., 2017; Munir et al., 2020) and the information requirements defined by the chemical industry (Seuring, 2003; Teufelhart, 2013). Data collection was conducted through semi-structured expert interviews among CREM professionals from the chemical industry. This approach was selected because it guarantees the eligibility of all interviewed experts due to their known identity and allows the inclusion of open questions and answers to derive recommendations for the implementation of AIR templates. Fig. 3 shows the work steps of the methodology. Each work step is further elaborated on in subsections 3.1 to 3.4.

3.1. Preparatory survey and literature review

Despite the focus of the study being the chemical industry, it cannot be assumed that all asset types in this industry sector have the same characteristics and information requirements. In work step 1.1, the expert panel was asked to name several recent construction projects from their respective organisation as candidates for investigation. The expert panel unanimously selected laboratory buildings for two reasons: firstly, they combine the structural properties of small chemical production facilities, storage units, and office buildings, secondly, they share many regulatory characteristics with each of those building types. A second survey among the expert panel subsequently identified four high-priority BIM Uses for investigation based on (Benn and Stoy, 2022). Work step 1.2 addressed RQ 1 through keyword literature reviews on the databases Web of Science (WoS) and Google Scholar. It aimed to identify relevant, peer-reviewed journal publications and academic publications in English or German between 2012 and 2022. The scope of the literature review included the following topics: "AIR for facility services", "Approaches to the generalisation of information requirements", and

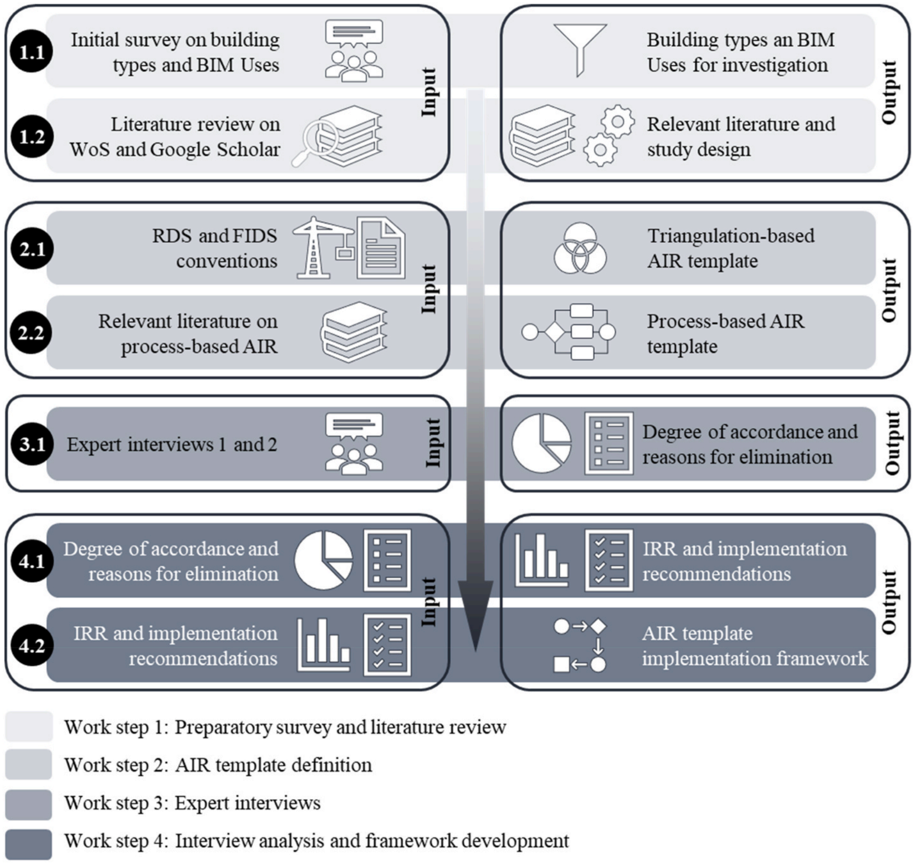

Fig. 3. Work steps of the methodology.

"CREM in the chemical industry". On the topic "AIR for facility services", a total of 6 publications were identified, they are further elaborated on in subsection 2.1. On the topic "Approaches to the generalisation of information requirements", a total of 12 publications were identified from which 7 were used as input for the present study, they are further elaborated on in subsection 2.2. On the topic "CREM in the chemical industry", a total of 5 publications were identified, they are further elaborated on in subsection 2.3.

3.2. AIR template definition

Work step 2 commenced with the division of the four selected BIM Uses into two triangulation-based and two process-based BIM Uses by the expert panel. Work step 2.1 included the definition of triangulation-based AIR templates, based on intersections between document-derived information requirements. Therefore, the expert panel was asked to provide the room data sheet (RDS) and facility identification system (FIDS) conventions from the selected laboratory construction projects. The selected projects were combined laboratory, office, and logistics buildings completed between 2016 and 2021, as shown in Table 1.

Table 1
Selected projects with project number (#), project description, activities, facility service provision model (FSPM), year of completion (YoC), and gross floor area (GFA).

#	Project description	Activities	FSPM	YoC	GFA
1	Mixed laboratory building	R&D, chemical laboratory, radioactivity laboratory, laboratory administration, storage of hazardous substances	Mainly external	2021	36,000 m^2
2	Clean room laboratory building	R&D, chemical laboratory, laboratory administration, storage of hazardous substances, logistics (automated guided vehicle)	Mainly external	2022	14,500 m^2
3	Laboratory administration with R&D units	R&D, laboratory administration, storage	Internal & external	2016	14,000 m^2

The comparative analysis of the provided documents was conducted in three steps: (1) Inventory and extraction of information requirements; (2) Mapping and harmonisation of information requirements; (3) Comparative analysis of intersections and divergences for Venn diagram creation. Triangulation-based AIR templates were then defined based on the Venn diagrams. Work step 2.2 included the definition of process-based AIR templates, aiming to generalise information requirements by developing simplified, literature-based process diagrams to derive information requirements. The process diagram development was conducted in three steps: (1) Identification of relevant literature on the BIM Uses "Maintenance cleaning management" and "Expert examination, inspection, and maintenance of conveyor systems" during work step 1.2 of the methodology; (2) Mapping and harmonisation of process steps and information requirements; (3) Comparative analysis and development of a literature-based process diagram and information requirements. Process-based AIR templates were then defined based on the process diagrams.

3.3. Expert interviews

Work step 3 included two expert interviews to assess the degrees of accordance of the AIR templates and to derive recommendations facilitating the implementation of AIR templates for CREM in the chemical industry. The expert panel was composed of 11 professionals responsible for the planning, operation, and maintenance of laboratories, office buildings, and chemical plants in three large, globally operating organisations in the chemical industry (OECD, 2023). The respective industry sectors of each organisation were defined based on the NACE Rev. 2 by the European Commission (European Commission, 2008): manufacture of textiles, apparel, leather and related products (CB); manufacture of chemicals and chemical products (CE); manufacture of pharmaceuticals, medicinal chemical and botanical products (CF); manufacture of machinery and equipment n.e.c. (not elsewhere classified) (CK); and manufacture of rubber and plastics products, and other non-metallic mineral products (CG). The experts were asked to state their respective organisation and its industry sector as well as their job title, position, years of experience in FM, and years of experience using BIM to ensure their eligibility as participants in the present study. Table 2 shows the anonymised background information of each interviewed expert.

The expert interviews were designed to accommodate the comparison of the inter-rater reliability (IRR) of all four AIR templates based on Fleiss' Kappa. This statistical measure is an expedient tool to assess the agreement coefficients of nominal ratings, that is, the assignment of categorical ratings to a number of items or classifying items, with 3 or more raters (Gwet, 2014). The design of the study was developed to facilitate the application of this method by evaluating each triangulation-based and process-based AIR template by a different set of experts, accommodating the condition of random sampling among raters (Fleiss, 1971). The interview guide was designed accordingly by establishing categorical "yes" and "no" ratings. During each interview, the expert panel was initially asked whether an information requirement is considered necessary for the execution of the respective process in their respective organisation. When the experts of an organisation considered the information requirement unnecessary, the reasons for its elimination were collected during the second part of the expert interview. The external validity of the research results, that is, the degree to which any conclusions drawn from the present study can be generalised to other settings, was augmented by addressing population validity and ecological validity during the interview preparation (Zeigler-Hill and Shackelford, 2017). Population validity, that is, the generalisability across people, was addressed by asking the participating organisation to choose their interview participants themselves, without pre-set eligibility criteria from the researchers. Ecological validity, that is, the generalisability across situations, was addressed by providing all relevant documents in advance. This allowed the experts to prepare for the interviews, avoiding incorrect answers due to unawareness of the examined information requirements. A pre-test was conducted to guarantee the comprehensibility of the interview guide and to assess the interview duration. Online meetings were selected for scheduling reasons. The expert interviews were conducted from November 2022 to February 2023. Due to the unequal number of experts per organisation, it was agreed that each organisation would have one vote in the expert interviews.

3.4. Interview analysis and framework development

Work step 4.1 commenced with the analysis and comparison of the inter-rater reliability of all four AIR templates by calculating Fleiss' Kappa based on their degrees of accordance. This approach was selected based on (Gwet, 2014). To address RQ 2, the most expedient approach to the generalisation of information requirements was then identified by assessing the strength of agreement between the raters based on (Landis and Koch, 1977). To address RQ 3, recommendations facilitating the implementation of AIR templates for CREM in the chemical industry were derived from the reasons for the elimination of information requirements. This approach was selected based on (Ullah et al., 2022; Tsay et al., 2022; Ashworth et al., 2019). Work step 4.2 addressed RQ 4 by translating the results of work step 4.1 into a 12-step framework formalising the implementation of AIR templates in the specific context of CREM in the chemical industry. This approach was selected based on (Matarneh et al., 2019b).

4. Results

4.1. AIR template definition

The expert panel was initially asked to identify BIM Uses for investigation based on (Benn and Stoy, 2022). Therefore, each BIM Use was assessed regarding its relevance for CREM in the chemical industry and the expected efficiency gains from its implementation. Four BIM Uses were identified for investigation based on the weighted mean of both assessments. Operational definitions for each BIM Use were defined based on (BIMe initiative, 2023; buildingSMART Finland, 2012; College of Engineering, 2021; Construction Industry Council, 2020). Table 3 shows the four selected BIM Uses and their operational definitions.

Several experts explicitly emphasised that they expect improved predictive maintenance of technical building services as well as a more cost-efficiency provision of facility services from the selected BIM Uses. The BIM Uses "Space and room management" and "Facility identification system for technical building services" were defined as inventory-based BIM Uses by the expert panel, meaning that they derive their information requirements from pre-existing documents, such as catalogues, naming conventions, or multiple facility services. This made them eligible for the triangulation-based approach. Fig. 4 shows the Venn diagrams of both BIM Uses, visualising the number of intersecting and diverging information requirements.

Diagram (a) "Space and room management" contains 64 information requirements after mapping and harmonisation. It should be noted that only about 20% (13 out of 64) are shared by all three organisations, whereas more than 68% (44 out of 64) are defined by one organisation.

Table 2
The expert panel with each expert's number (#), respective organisation, industry sector, job title, position, years of FM experience (FM exp.), years of BIM experience (BIM exp.) and expert interview participation (EIP).

#	Organisation	Industry sector	Job title	Position	FM exp.	BIM exp.	EIP
1	A	CE, CF	Head of CAFM and space management	Management	20	3.5	1
2	A	CE, CF	Team leader CAFM	Management	5	2.5	1
3	A	CE, CF	Team leader space management	Management	2	1	1
4	A	CE, CF	Project operations manager	Operational	4	5	2
5	B	CB, CE, CK	Project manager	Operational	6	2	1
6	B	CB, CE, CK	Facility manager	Operational	5	2	2
7	B	CB, CE, CK	Senior project manager	Management	25	5	1
8	B	CB, CE, CK	Facility manager	Management	2	0	2
9	C	CE, CF, CG	Plant engineer	Operational	2.5	2.5	2
10	C	CE, CF, CG	Facility services	Operational	22	4	1
11	C	CE, CF, CG	Technical management	Management	15	1	2

Table 3
Selected BIM Uses and their operational definitions.

BIM Use	Operational definition
Space and room management	- Derivation of room books, space occupancy, and vacancy rates - Model-based updating of the current space occupancy and vacancy - Model-based space analysis and controlling, space demand determination, space demand planning, space demand verification, space occupancy planning, and simulation of different occupancy scenarios
Maintenance cleaning management	- Model-based planning and coordination of maintenance cleaning - Derivation of quantities, masses, surface materials, and cleaning cycles
Facility identification system for technical building services	- Model-based identification of the components and installations in an asset - Model-based updating of the asset identification, room allocation in the model, and component-and plant-specific attributes
Expert examination, inspection, and maintenance of conveyor systems	- Model-based planning and coordination of expert examinations, inspections, and maintenance of conveyor systems following public regulations and subsequent tracking of identified defects - Virtual development of a concept for expert examinations, inspections, and maintenance

Diagram (b) “Facility identification system for technical building services” contains 31 information requirements after mapping and harmonisation. Larger intersections can be seen, as 32% (10 out of 31) are shared by all three organisations and the same amount of 32% (10 out of 31) are defined by one organisation. A strictly triangulation-based approach to the definition of AIR templates would select the information requirements occurring in all three RDS and FIDS conventions to generalise 13 information requirements for the BIM Use “Space and room management” and 10 for the BIM Use “Facility identification system for technical building services”. However, such an approach would effectively ignore 80% (a) and 68% (b) of the proposed information requirements. The BIM Uses “Maintenance cleaning management” and “Expert examination, inspection, and maintenance of conveyor systems” were defined as process-based BIM Uses by the expert panel. Fig. 5 shows the process diagrams of both BIM Uses. Figs. 11 and 12 in the appendix show both process diagrams in higher resolution. The literature used as input for the development of each process diagram includes (Bartels, 2020; Feller, 2020a; Godager et al., 2021) for (a) “Maintenance cleaning management” and (Bartels, 2020; Dias and Ergan, 2020; Feller, 2020b) for (b) “Expert examination, inspection, and maintenance of conveyor systems”.

Diagram (a) “Maintenance cleaning management” is mapped as a 13-step horizontal flow chart with two lanes for the relevant stakeholders: the client or the client’s CREM department (top lane) and the external service provider (bottom lane). Since the expert panel chose an input-

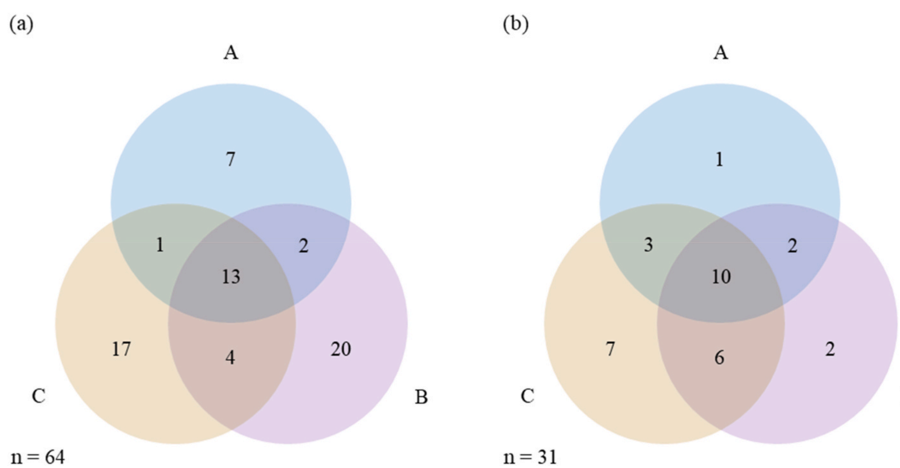

Fig. 4. Venn diagrams of the BIM Uses (a) “Space and room management” and (b) “Facility identification system for technical building services” based on RDS and FIDS conventions provided by the participating organisations.

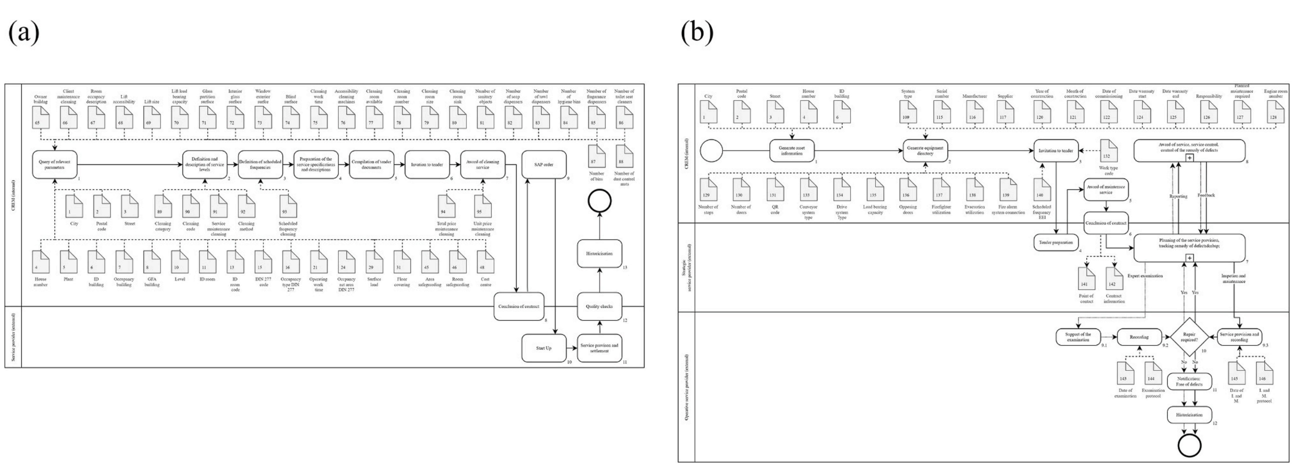

Fig. 5. Process diagrams of the BIM Uses (a) “Maintenance cleaning management” and (b) “Expert examination, inspection, and maintenance of conveyor systems”. Please see Fig. 11 and 12 in the appendix for higher resolution.

oriented service-level approach, the two process steps “Definition and description of service levels” (Step 2) and “Definition of scheduled frequencies” (Step 3) specify the required services and the way they should be performed (Talamo and Atta, 2019). A total of 51 information requirements were derived. Diagram (b) “Expert examination, inspection, and maintenance of conveyor systems” is mapped as a 14-step horizontal flow chart with three lanes for the relevant stakeholders: the client or the client’s CREM department (top lane), the external strategic service provider (middle lane), and the external operative service provider (bottom lane). The panel agreed to further differentiate the different aspects of this BIM Use by dividing Step 9 into three sub-steps:

- “Expert examination” is specified in Steps 9.1 and 9.2. It describes the examination of the asset by a certified expert witness within the context of the legally required certifications for the operations of conveyor systems;
- “Inspection and maintenance” are specified in Step 9.3. It describes the regular inspection and maintenance of conveyor systems by an internal or external service provider to ensure their trouble-free operations.

The expert panel chose an input-oriented service-level approach for this BIM Use as well. Hence, the process step “Invitation to tender” (Step 3) includes a “Work type code” defining the required services, frequencies, and conditions to facilitate the tender process. A total of 31 information requirements were derived.

4.2. Interview results

Interview 1 addressed the space-related BIM Uses “Space and room management” and “Maintenance cleaning management”. Interview 2 addressed the MEP-related BIM Uses “Facility identification system for technical building services” and “Expert examination, inspection, and maintenance of conveyor systems”. Table 6 in the appendix shows all identified information requirements and the respective answers given by the expert panel for each BIM Use. Based on the results of interview 1, the degrees of accordance of the AIR templates for space-related BIM Uses were assessed, as shown in Fig. 6.

The AIR template for “Space and room management” defines a total of 64 information requirements, scoring the following degree of accordance: the largest share at 41% of the information requirements (=26) are considered necessary by all three organisations (3/3 Org.), 31% (=20) by two organisations (2/3 Org.), 19% (=12) by one organisation (1/3 Org.), and the smallest share at 9% (=6) by no organisation (0/3 Org.). The information requirements considered necessary by all three organisations include the location, size, coverings, occupancy, fire protection, safeguarding, special occupancy permissions, and construction requirements, as shown in Table 6. The AIR template for “Maintenance cleaning management” defines a total of 51 information requirements, scoring the following degree of accordance: the largest share at 74% of the information requirements (=38) are considered necessary by all three organisations (3/3 Org.), 10% (=5) by two organisations (2/3 Org.), the smallest share at 6% (=3) by one organisation (1/3 Org.), and 10% (=5) by no organisation (0/3 Org.). The information requirements considered necessary by all three organisations include the location, size, coverings, occupancy, safeguarding, lift availability, cleaning room availability, and specific cleaning methods and frequencies, as shown in Table 6. Based on the results of interview 2, the degrees of accordance of the AIR templates for MEP-related BIM Uses were assessed, as shown in Fig. 7.

The AIR template for “Facility identification system for technical building services” defines a total of 31 information requirements, scoring the following degree of accordance: the largest share at 48% of these information requirements (=15) are considered necessary by all three organisations (3/3 Org.), 32% (=10) by two organisations (2/3 Org.), 13% (=4) by one organisation (1/3 Org.), and the smallest share at 7% (=2) by no organisation (0/3 Org.). The information requirements considered necessary by all three organisations include the location, system ID, system status, cost group, element-specific product data, warranty, and responsibility, as shown in Table 6. The AIR template for “Expert examination, inspection, and maintenance of conveyor systems” defines a total of 35 information requirements, scoring the following degree of accordance: the largest share at 63% of the information requirements (=22) are considered necessary by all three organisations (3/3 Org.), 8% (=3) by two organisations (2/3 Org.), the smallest share at 6% (=2) by one organisation (1/3 Org.), and 23% (=8) by no organisation (0/3 Org.). The information requirements considered necessary by all three organisations include the location, element-specific product data, warranty, responsibility, construction, loading capacity, fire protection, and scheduled frequencies, as shown in Table 6. It should be noted that the information requirements agreed on by all three organisations were mainly static data, that is, data that is available after handover and commissioning and likely to remain unchanged during the life cycle. (International Organisation for Standardisation, 2021) In contrast, most information requirements eliminated by all three organisations concerned dynamic data, that is, data that requires continuous or frequent updating, as it is the result of sensor surveillance, inspections, or frequent processes. The inter-rater reliability of the triangulation-based and the process-based AIR templates was then assessed by calculating Fleiss’ Kappa (κ) using the following formulas:

$$\kappa = \frac{\overline{P} - \overline{P_e}}{1 - \overline{P_e}} \tag{1}$$

$$p_j = \frac{1}{Nn}\sum_{j=1}^{N} n_{ij}, 1 = \sum_{j=1}^{k} p_j \tag{2}$$

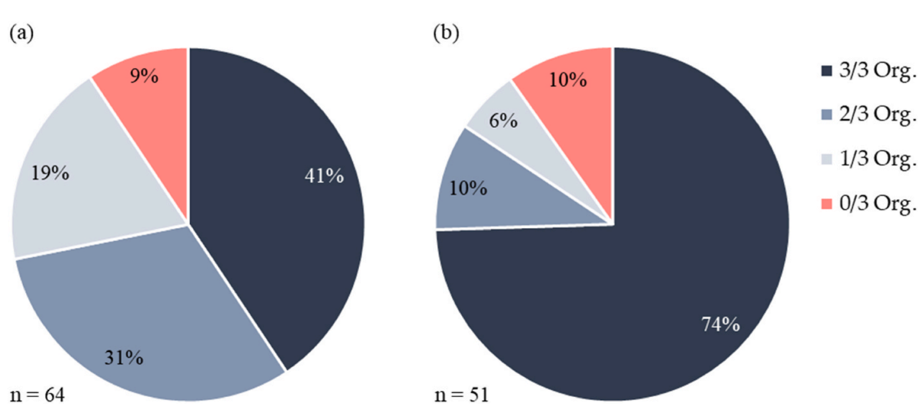

Fig. 6. Degrees of accordance of the AIR templates for (a) “Space and room management” and (b) “Maintenance cleaning management” based on interview 1.

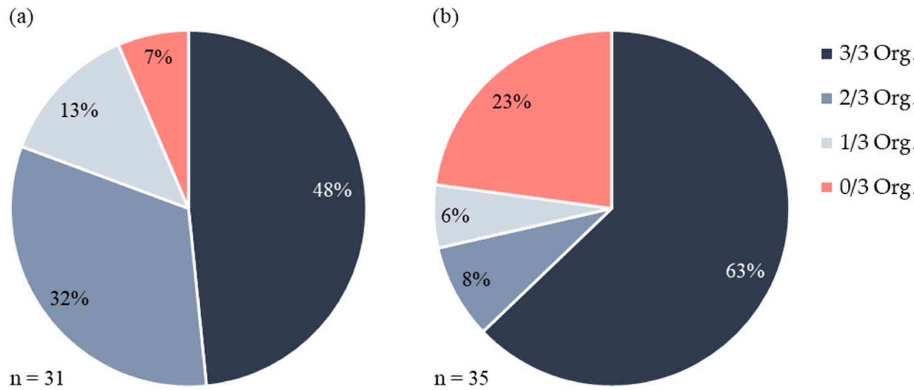

Fig. 7. Degrees of accordance of the AIR templates for (a) "Facility identification system for technical building services" and (b) "Expert examination, inspection, and maintenance of conveyor systems" based on interview 2.

$$P_i = \frac{1}{n(n-1)} \tag{3}$$

$$\overline{P} = \frac{1}{N}\sum_{i=1}^{N} P_i \tag{4}$$

$$\overline{P_e} = \frac{1}{N}\sum_{j=1}^{N} p_j^2 \tag{5}$$

$\overline{P}$ represents the mean of the $P_i^{'}s$ and $\overline{P_e}$; P_i the extent to which raters agree for the i-th subject; $\overline{P_e}$ the hypothetical probability of chance agreement; p_j the proportion of all assignments which were to the j-th category; N the total number of subjects; n the number of ratings per subject; k the number of categories into which assignments are made; i the subjects; j the categories of the scale; n_{ij} the number of raters who assigned the i-th subject to the j-th category. Fig. 8 shows Fleiss' Kappa of the triangulation-based and the process-based AIR templates.

It shows that Fleiss' Kappa is $\kappa = 0.26$ for triangulation-based AIR templates and $\kappa = 0.70$ for process-based AIR templates. By interpreting Fleiss' Kappa based on (Landis and Koch, 1977), the inter-rater reliability for both approaches can be assessed, as shown in Table 4.

When considering the underlying approaches, it becomes apparent that the inter-rater reliability of the process-based AIR templates indicates "substantial agreement" in contrast to the inter-rater reliability of the triangulation-based AIR templates indicating only "slight agreement". These results reveal that process-based AIR templates score a considerably higher agreement among CREM professionals responsible for the planning, operation, and maintenance of laboratories, office buildings, and chemical plants. This suggests a much greater generalisability and accuracy of process-based AIR templates for CREM in the chemical industry, answering RQ 2. During the second part of the expert interviews, the expert panel was asked to provide a reason for each elimination of an information requirement from the AIR templates. When an information requirement was eliminated by all three organisations, three answers were collected. Fig. 9 shows the results of this survey.

Table 4
Interpretation of Fleiss' Kappa based on (Landis and Koch, 1977).

Value of Fleiss' Kappa	Strength of agreement
<0	Poor
0.00–0.20	Fair
0.21–0.40	Slight
0.41–0.60	Moderate
0.61–0.80	Substantial
0.81–1.00	Almost Perfect

To answer RQ 3, recommendations facilitating the implementation of AIR templates for CREM in the chemical industry were derived from the reasons given by the expert panel. Recommendation 1 derives from the most frequently given reason, as some information may be necessary for the respective process but ineligible for the delivery, storage, or management in an AIM. Recommendation 2 derives from the observation that this may concern all dynamic data, favouring static data for BIM-based delivery when defining AIR templates for CREM in the chemical industry. Recommendation 3 derives from the second most frequent reason, referring to the categorical necessity of an information requirement for the respective process. Recommendation 4 derives from the third most frequent reason, highlighting that some information requirements are only considered necessary in the context of specific asset types or sub-types. Recommendation 5 derives from the least frequent reason, indicating the need to include further experts from other departments. Table 5 shows the derived recommendations.

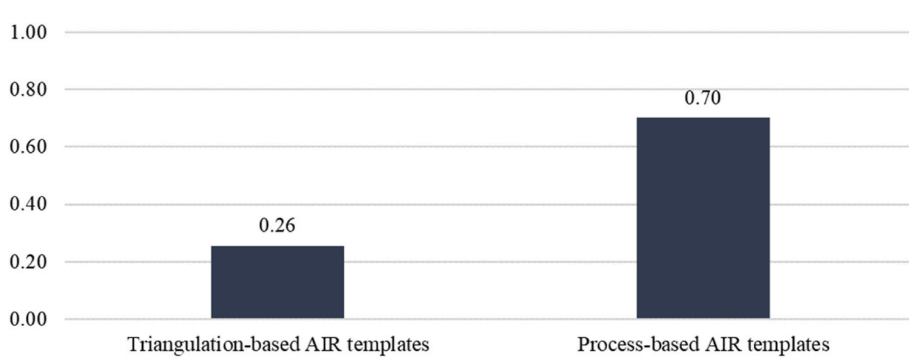

Fig. 8. Fleiss' Kappa of the triangulation-based and the process-based AIR templates based on the results of interviews 1 and 2.

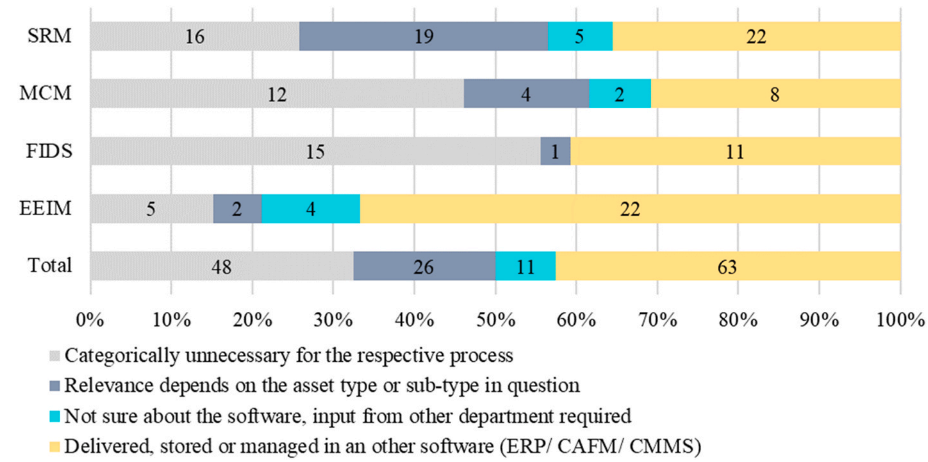

Fig. 9. Mentions of the reasons for the elimination of information requirements in proportion based on the AIR templates for the BIM Uses "Space and room management" (SRM); "Maintenance cleaning management" (MCM); "Facility identification system for technical building services" (FIDS); "Expert examination, inspection, and maintenance of conveyor systems" (EEIM); and total mentions (Total).

Table 5
Recommendations facilitating the implementation of AIR templates for CREM in the chemical industry.

#	Recommendation
1	Software for the delivery, storage or management of each information requirement should be identified in advance
2	Static data should be prioritised for BIM-based delivery when defining and implementing AIR templates
3	Accuracy limitations of process-based AIR templates require customisation before implementation
4	Specific asset type or sub-type of the asset in question should be defined in advance
5	Stakeholders from all relevant CREM departments should be involved in the implementation process

5. Framework

To translate the results of RQ 1 to 3 into a user-centric AIR template implementation framework for CREM in the chemical industry, the recommendations were initially translated into a three-stage structure:

(1) Customisation: Provision of a BIM Use-specific AIR template containing a pre-defined process diagram and pre-defined information requirements. The information requirements should contain all possibly relevant information regarding the location, physical properties, and occupancy characteristics on the one hand, and hygiene-, safety-, and maintenance-related characteristics on the other. The process diagram serves as input to identify the relevant assets and to apply further customisations, addressing Recommendations 3 and 4.
(2) Selection: Extraction of all customised information requirements from the customised process diagram, involvement of all relevant stakeholders, and identification of BIM-based information requirements. This step might also entail a differentiation between static and dynamic data. This step provides all BIM-based information requirements for further processing, addressing Recommendations 1, 2 and 5.
(3) Mapping: Definition of the respective BIM authoring software data type, element category, instance or parameter type, responsibility, and time of delivery of each BIM-based information requirement for the creation of BIM Use- and asset (sub-) type-specific AIR.

As CREM professionals in the chemical industry often struggle with a lack of guides on the effective implementation of BIM Use-specific AIR, the proposed structure was further translated into a user-centric framework, as shown in Fig. 10. It defines and describes each step and document necessary to convert an AIR template into customised AIR for implementation in the chemical industry. It adopts a user-centric approach and focuses entirely on the owner-operator perspective. The 12-step framework is designed as a vertical flow chart with three lanes representing the three relevant stakeholders: the internal CREM department (left lane), the internal or external BIM manager (middle lane), and the external design offices and building contractors responsible for the creation and delivery of the BIM Use-specific information requirements (IR) (right lane). Each stage of the framework is further elaborated on in subsections 5.1 to 5.3.

5.1. Process and information requirement customisation

Stage 1 of the framework addresses the need to initially customise the provided AIR template. Therefore, it focuses on the need to define the relevant asset (sub-) types based on Recommendation 4. This establishes that only BIM Use- and asset (sub-) type-relevant information requirements are considered in the subsequent steps. Steps 2 to 6 address the need for individual customisation of the pre-defined process diagram and the pre-defined information requirements based on Recommendation 3, ensuring that the process diagram reflects the organisation-specific process. All steps in Stage 1 are conducted by the internal CREM department to maintain the owner-operator perspective. Using the example of the BIM Use "Maintenance cleaning management", Step 1 could entail the limitation on laboratory spaces while Steps 2 to 6 entail the addition of laboratory-specific cleaning steps.

5.2. Information requirement selection

Stage 2 of the framework addresses the need to select all BIM-based information requirements based on the organisation's specific data management structures. Step 7 focuses on the assignment of responsibilities to each information requirement to identify relevant software based on Recommendation 5, assuring the integration of all relevant experts into the process. Step 8 addresses the identification of relevant software for each information requirement in the context of the organisation's data management structures and information flow based on Recommendations 1 and 2. After identifying relevant software for each information requirement, BIM-based information requirements can be selected based on available interfaces, possible information exchange, or compatibility with IFC or other exchange formats. This assures that only processable BIM-based information requirements are

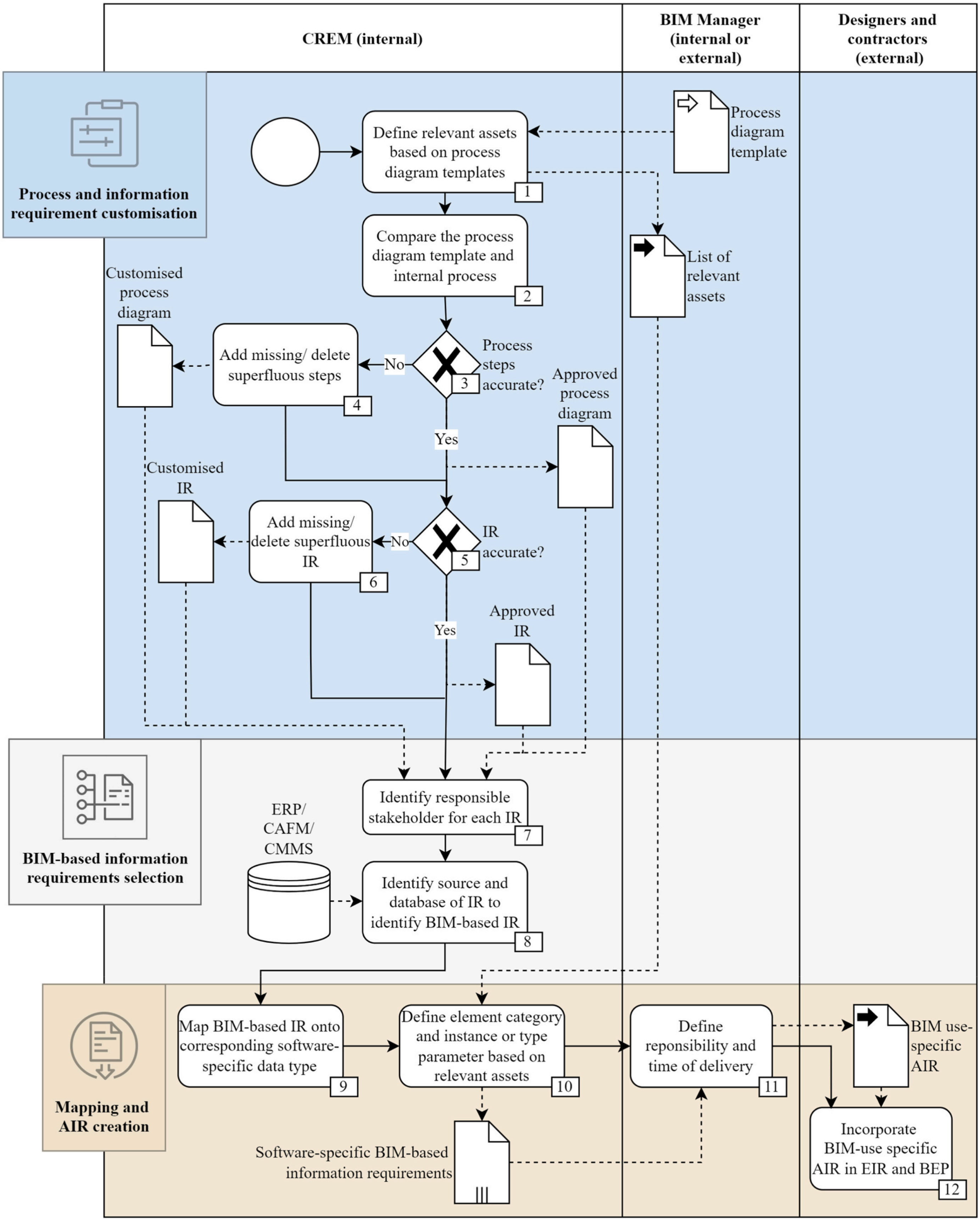

Fig. 10. User-centric AIR template implementation framework for CREM in the chemical industry.

considered in the subsequent steps. Using the example of the BIM Use "Maintenance cleaning management", Step 7 could entail the assignment of responsibilities to the FM department charged with the provision of cleaning services while Step 8 could entail the above-described identification of BIM-based information requirements.

5.3. Mapping and AIR creation

Stage 3 of the framework addresses the need to map all BIM-based information requirements onto software-specific data types and to derive project-specific AIR for implementation. Steps 9 and 10 focus on the initial mapping of each BIM-based information requirement onto the corresponding data type, element category and instance- or type-parameters in the selected BIM authoring software, ensuring trouble-free editing and IFC export. Step 11 defines the responsibility and time of delivery for each information requirement, ensuring that project-specific adjustments can be made in consideration of the individual project execution. Step 12 completes the framework by incorporating the customised AIR into the project's EIR and BIM execution plan (BEP). Using the example of the BIM Use "Maintenance cleaning management", Step 9 could include the mapping of the information requirement "gross planned area" onto the data type "area" in an authoring software while Step 10 could map it onto a room-related instance parameter. Steps 11 and 12 could then encompass the above-described project-specific steps.

The framework illustrates how AIR templates containing pre-defined process diagrams and information requirements can be implemented to support CREM professionals in the chemical industry, answering RQ 4.

6. Discussion

The prioritised BIM Uses and their expected benefits align with the results of relevant research, emphasising the significance of the trouble-free operations of technical building services and the efficient provision of facility services in the chemical industry (Braun et al., 2022; Chin et al., 2020; Teufelhart, 2013; Tong et al., 2019). Two approaches to the generalisation of information requirements were identified, applied and compared based on the selected and eliminated information requirements. The information requirements considered necessary concur with (Sheward, 2021; Tong et al., 2019), highlighting the importance of hygiene-, safety-, and maintenance-related information for facility services in the chemical industry. Many of the identified information requirements are expected to be valid for other industry sectors as well, for instance, location, size, coverings or occupancy. Further research might investigate the intersections between different industry sectors to identify common "base AIR" and additional, industry-specific "AIR extensions". Such an approach might also be applied to the proposed AIR template implementation framework, as minor adjustments and extensions may allow its application in other industry sectors. However, an approach investigating every single industry sector by itself may not be the most efficient way to promote BIM implementation on a large scale. Further research might investigate the extent to which AIR templates can be clustered for related industry sectors, based on the nature of their core business. Such an approach could aim to find a balance between industry-specific AIR templates accommodating the unique characteristics of different industry sectors, as pointed out by (Cavka et al., 2017; Munir et al., 2020), while keeping any implementation guides as simple and general as possible. The results show that a process-based approach yields more accurate and, therefore, more generalisable AIR templates for CREM in the chemical industry. This outcome is unanticipated, as the documents used for the triangulation-based AIR templates were provided by the same organisations that assessed the accuracy of the extracted information requirements. This indicates that RDS and FIDS conventions may be too organisation- and/or project-specific compared to simplified process diagrams. However, the reasons for the elimination of information requirements shown in Fig. 10 only partially support that explanation. For the BIM Use "Facility identification system for technical building services", this reasoning is plausible, as nearly 60% of the proposed information requirements were eliminated because they were categorically unnecessary. This is not the case for the BIM Use "Space and room management", as the specific asset in question is nearly as decisive as the information requirements' categorical necessity. This suggests that further research on generalisable, BIM Use-specific information requirements for different asset types and sub-types is needed. It also partially concurs with the findings of (Tong et al., 2019) indicating that frameworks or AIR templates will always maintain a certain inaccuracy, thus, require individual customisation regardless of the number of asset (sub-) types covered. Further research might focus more on the relevant asset (sub-) types for a specific BIM Use. Such research could lead to comprehensive, industry-specific catalogues of "must-have" information requirements for an overall asset type, for instance, conveyor systems, serving as root for specified, customisable information requirements for its sub-types, for instance, passenger lifts or goods lifts. Implementing such information requirements into current object libraries could further enhance the applicability of AIR templates, as proposed by (Pasini et al., 2017). A total of five recommendations facilitating the implementation of AIR templates for CREM in the chemical industry were derived. As pointed out by (Sacks et al., 2020), BIM offers considerable potential to bridge the gap between the construction phase and the operational phase. Against this backdrop, the identification of relevant software described in Recommendation 1 requires careful analysis of information management processes, as virtually all organisations in the chemical industry have existing ERP, CAFM, and CMMS software structures. BIM-based information input will need to adjust to and fit into those structures, either as an additional platform or as a data repository (Hewavitharana and Perera, 2020). Recommendation 2 strongly concurs with the results of (Santos, 2009), stating that static data are to be prioritised when defining and implementing AIR templates. In the context of the chemical industry and its focus on maintenance processes, static data based on AIR templates could constitute the basis for BIM-based maintenance, corresponding to the results of (Chin et al., 2020). Future applications for predictive maintenance might also rely equally on technologies like big data, the Internet of things (IoT) or sensors. Further research might define the optimal niche that BIM could occupy as a transfer tool for CREM in the chemical industry, conveying static data from the construction phase to the operational phase. Such research might not only define specific BIM-based information requirements but consider related data exchange and interface problems too, as pointed out by (Chen and Tserng, 2017; Matarneh et al., 2019a; Nojedehi et al., 2022). Regarding the accuracy limitations of process-based AIR templates, Recommendation 3 affirms the findings of (Munir et al., 2020) concluding that "it may not be possible to develop a rigid list of requirements that apply to all asset owners." However, the results also show that hygiene-, safety-, and maintenance-related information requirements apply to all participating organisations, concurring with (Agung and Siahaan, 2020; Tong et al., 2019). The definition of as-accurate-*as*-possible AIR templates may be the most advantageous way to guide CREM professionals in the chemical industry, as a "one size fits all" approach is unlikely to succeed. Further research might increase the accuracy of the present results by including more organisations in the chemical industry. Also, it might consider regional or national regulations to facilitate AIR customisation in different regions or countries. Recommendation 4 concerns the initial definition of the specific asset type or sub-type, as described above. Recommendation 5 concurs with the results of (Sheward, 2021) indicating that late and insufficient stakeholder involvement often leads to suboptimal decision-making. At the same time, it addresses the complex stakeholder structure pointed out by (Blackburn et al., 2015; Little et al., 2023). Further research might investigate how early stakeholder involvement can be achieved in the most efficient and streamlined way while balancing competing interests. This might be achieved by further developing the concept of a "computational design assistant" for facility services, based on (Sheward, 2021).

7. Limitations

The following limitations are to be acknowledged and may affect the results of the present study:

(1) The extent to which the proposed framework can be generalised to all organisations in the chemical industry may be affected by the number of organisations and professionals involved. Even though the external validity of the research results was augmented by ensuring population validity and ecological validity, the results cannot be considered representative of the entire chemical industry. This is because the number of potential participants available to support research in this field is highly limited. Further research might involve a higher number of organisations and stakeholders.
(2) The extent to which the defined AIR templates can be generalised to all building types in the chemical industry may be affected by the fact that all RDS and FIDS came from laboratory construction projects. Despite the above-described structural properties and regulatory characteristics of this building type, it cannot be considered representative of all building types in the chemical industry. Further research might involve a higher number of building types.
(3) Only four BIM Uses were investigated in the present study. The suitability of the process-based approach and its expediency for further BIM Uses may be limited. It is not ascertained whether the proposed approach also produces satisfying results when applied to different facility processes and BIM Uses. Further research might address this limitation by applying the proposed approach to other facility services.
(4) The process diagrams developed in the present study follow an input-oriented service-level approach. Different organisations may choose alternative approaches, for instance, output-oriented service level approaches. This limitation is the result of the participating organisations' preference for an input-oriented service approach. Further research could address this limitation by investigating how different service level approaches affect the way organisations select information requirements.

8. Conclusion

As academic research and relevant organisations promote the utilization of BIM for the operational phase, research on BIM implementation for CREM is underrepresented, especially in the chemical industry. Given the specific safety-, hygiene-, and maintenance-related requirements, AIR definition in this context requires considerable effort and experience. The present study addresses the following research gaps: a lack of AIR templates and implementation guides in the context of CREM in the chemical industry, diverging approaches to the definition of AIR templates, and the link between an organisation's industry and its information requirements. Therefore, four research questions were defined and answered:

RQ 1: Which approaches to the generalisation of information requirements for BIM Uses exist?

RQ 2: Which is the most expedient approach to the definition of AIR templates for CREM in the chemical industry?

RQ 3: Which recommendations are necessary to facilitate the implementation of AIR templates for CREM in the chemical industry?

RQ 4: Which steps are necessary to formalise the implementation of AIR templates for CREM in the chemical industry?

The results show that process diagrams are an expedient approach to the definition of AIR templates, as they produced more accurate, thus, more generalisable AIR templates for CREM in the chemical industry. In addition, it shows that safety-, hygiene-, and maintenance-related information is of particular importance for the provision of facility services in the chemical industry and that static data is to be prioritised for BIM-based information delivery. Recommendations facilitating the implementation of AIR templates in this context concern software for information delivery, storage or management; the prioritisation of static data; accuracy limitations of AIR templates; the consideration of asset types and sub-types; and stakeholder involvement. Three stages are necessary to formalise the implementation of AIR templates based on these recommendations: customisation, selection, and mapping. The present study provides the following contributions:

(1) The identification and application of an expedient approach to the definition of AIR templates for CREM in the chemical industry;
(2) The provision of a first iteration of AIR for four BIM Uses;
(3) A user-centric AIR template implementation framework for CREM in the chemical industry as an implementation guide for the autonomous customisation and implementation of AIR templates.

As BIM implementation in the operational phase progresses, CREM in the chemical industry needs to find ways to achieve this goal while accommodating its unique characteristics and challenges. However, it is unlikely that overly specific or elaborate templates or implementation guides will be suitable for the heterogeneous landscape of contemporary CREM. The present study incentivises professionals to adopt a process-based approach utilizing pre-defined process diagrams as a first foothold for further customisation. The definition of process-based AIR templates may provide the necessary tools to independently tackle pilot projects, paving the way for BIM implementation in CREM in the chemical and other industries. The results of the present study suggest that a wider approach to the definition of AIR templates and implementation guides might be appropriate. Further research might discern the precise delimitations between different "industry clusters" and asset (sub-) types to identify "base AIR" for both categories, serving as nuclei for modular or branched specification and customisation structures. Associations like (Deutsches Institut für Normung e.V., 2021), (buildingSMART International, 2023) or (BIMe initiative, 2023) might develop corresponding object libraries or design assistants to facilitate the provision, customisation, and implementation of AIR templates for clients, owners, and operators in the chemical and other industries.

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Declaration of competing interest

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

Data availability

Data will be made available on request.

Appendix

Table 6
Necessity of each information requirement for each organisation (Org.) for each BIM Use ("x" = necessary and "o" = not necessary) and the respective degree of accordance (DoA).

#	Information requirement	Space and room management				Maintenance cleaning management				Facility identification system for building services				Exp. Exam., inspection, and maintenance of conveyor systems			
		Org.			DoA	Org.			DoA	Org.			DoA	Org.			DoA
		A	B	C		A	B	C		A	B	C		A	B	C	
1	City	x	x	x	3/3	x	x	x	3/3	-	-	-	-	x	x	x	3/3
2	Postal code	x	x	x	3/3	x	x	x	3/3	-	-	-	-	x	x	x	3/3
3	Street	x	x	x	3/3	x	x	x	3/3	-	-	-	-	x	x	x	3/3
4	House number	x	x	x	3/3	x	x	x	3/3	-	-	-	-	x	x	x	3/3
5	Plant	x	x	x	3/3	x	x	x	3/3	x	x	o	2/3	-	-	-	-
6	ID building	x	x	x	3/3	x	x	x	3/3	x	x	o	2/3	x	x	x	3/3
7	Occupancy building	o	x	o	1/3	x	x	o	2/3	-	-	-	-	-	-	-	-
8	GFA building	o	x	o	1/3	o	x	x	2/3	-	-	-	-	-	-	-	-
9	Status room	o	o	o	0/3	-	-	-	-	-	-	-	-	-	-	-	-
10	Level	x	x	x	3/3	x	x	x	3/3	x	x	x	3/3	-	-	-	-
11	ID room	x	x	x	3/3	x	x	x	3/3	x	x	x	3/3	-	-	-	-
12	Room number door label	o	o	x	1/3	-	-	-	-	-	-	-	-	-	-	-	-
13	ID room code	o	o	x	1/3	o	o	x	1/3	-	-	-	-	-	-	-	-
14	Room reference	x	x	o	2/3	-	-	-	-	-	-	-	-	-	-	-	-
15	DIN 277 code	x	o	x	2/3	x	x	x	3/3	-	-	-	-	-	-	-	-
16	Occupancy type DIN 277	o	x	x	2/3	x	x	x	3/3	-	-	-	-	-	-	-	-
17	Date of room commissioning	o	x	x	2/3	-	-	-	-	-	-	-	-	-	-	-	-
18	Date of room decommissioning	o	o	o	0/3	-	-	-	-	-	-	-	-	-	-	-	-
19	Status refurbishment	o	o	o	0/3	-	-	-	-	-	-	-	-	-	-	-	-
20	Date of refurbishment	o	o	o	0/3	-	-	-	-	-	-	-	-	-	-	-	-
21	Operating work time	x	x	x	3/3	x	x	x	3/3	-	-	-	-	-	-	-	-
22	Door number	x	x	o	2/3	-	-	-	-	-	-	-	-	-	-	-	-
23	Gross planned area	x	x	x	3/3	-	-	-	-	-	-	-	-	-	-	-	-
24	Occupancy net area DIN 277	x	x	x	3/3	o	x	x	2/3	-	-	-	-	-	-	-	-
25	Additional occupancy permissions	x	x	x	3/3	-	-	-	-	-	-	-	-	-	-	-	-
26	Occupancy net planned area GIF	o	x	o	1/3	-	-	-	-	-	-	-	-	-	-	-	-
27	Minimum headroom	o	x	x	2/3	-	-	-	-	-	-	-	-	-	-	-	-
28	Finished floor level	x	o	x	2/3	-	-	-	-	-	-	-	-	-	-	-	-
29	Surface load	x	o	x	2/3	x	x	x	3/3	-	-	-	-	-	-	-	-
30	Point load	x	o	x	2/3	-	-	-	-	-	-	-	-	-	-	-	-
31	Floor covering	x	x	x	3/3	x	x	x	3/3	-	-	-	-	-	-	-	-
32	Wall covering	x	x	x	3/3	-	-	-	-	-	-	-	-	-	-	-	-
33	Ceiling covering	x	x	x	3/3	-	-	-	-	-	-	-	-	-	-	-	-
34	Fire protection restriction	x	o	x	2/3	-	-	-	-	-	-	-	-	-	-	-	-
35	Fire protection zone	x	x	x	3/3	-	-	-	-	-	-	-	-	-	-	-	-
36	Escape route	x	x	x	3/3	-	-	-	-	-	-	-	-	-	-	-	-
37	Sprinkler protection	x	x	x	3/3	-	-	-	-	-	-	-	-	-	-	-	-
38	Increased construction requirement	x	x	x	3/3	-	-	-	-	-	-	-	-	-	-	-	-
39	Rentable	x	o	x	2/3	-	-	-	-	-	-	-	-	-	-	-	-
40	Status renting	o	o	o	0/3	-	-	-	-	-	-	-	-	-	-	-	-
41	Occupancy number is	o	o	o	0/3	-	-	-	-	-	-	-	-	-	-	-	-
42	Occupancy number maximum	x	x	x	3/3	-	-	-	-	-	-	-	-	-	-	-	-
43	Workplace number	x	x	x	3/3	-	-	-	-	-	-	-	-	-	-	-	-
44	Room owner	o	o	x	1/3	-	-	-	-	-	-	-	-	-	-	-	-
45	Area safeguarding	x	x	x	3/3	x	x	x	3/3	-	-	-	-	-	-	-	-
46	Room safeguarding	x	x	x	3/3	x	x	x	3/3	-	-	-	-	-	-	-	-
47	Room access authorisation	x	x	x	3/3	-	-	-	-	-	-	-	-	-	-	-	-
48	Cost centre	o	o	x	1/3	x	x	x	3/3	-	-	-	-	-	-	-	-
49	Space temperature	x	x	x	3/3	-	-	-	-	-	-	-	-	-	-	-	-
50	Space temperature max	x	x	o	2/3	-	-	-	-	-	-	-	-	-	-	-	-
51	Space temperature min	x	x	o	2/3	-	-	-	-	-	-	-	-	-	-	-	-
52	Air conditioning	o	x	x	2/3	-	-	-	-	-	-	-	-	-	-	-	-
53	Multi-space	o	o	x	1/3	-	-	-	-	-	-	-	-	-	-	-	-
54	Heated	x	x	o	2/3	-	-	-	-	-	-	-	-	-	-	-	-

55	Cooled	x	x	o	2/3	-	-	-	-	-	-	-	-	-	-	-	-
56	Ventilated	o	x	x	2/3	-	-	-	-	-	-	-	-	-	-	-	-
57	Room air quality requirements	o	x	o	1/3	-	-	-	-	-	-	-	-	-	-	-	-
58	Sanitary installations in the room	x	o	o	1/3	-	-	-	-	-	-	-	-	-	-	-	-
59	Daylight	x	o	o	1/3	-	-	-	-	-	-	-	-	-	-	-	-
60	Sun protection available	x	o	o	1/3	-	-	-	-	-	-	-	-	-	-	-	-
61	Shading device type	x	o	o	1/3	-	-	-	-	-	-	-	-	-	-	-	-
62	Dust-free room class	o	o	x	1/3	-	-	-	-	-	-	-	-	-	-	-	-
63	Room movable furnishing	x	x	x	3/3	-	-	-	-	-	-	-	-	-	-	-	-
64	Room fixed furnishing	x	x	x	3/3	-	-	-	-	-	-	-	-	-	-	-	-
65	Owner building	-	-	-	-	o	o	x	1/3	-	-	-	-	-	-	-	-
66	Client maintenance cleaning	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
67	Room occupancy description	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
68	Lift accessibility	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
69	Lift size	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
70	Lift load-bearing capacity	-	-	-		x	x	x	3/3	-	-	-	-	-	-	-	-
71	Glass partition surface	-	-	-	-	o	o	o	0/3	-	-	-	-	-	-	-	-
72	Interior glass surface	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
73	Window exterior surface	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
74	Blind surface	-	-	-	-	o	o	x	1/3	-	-	-	-	-	-	-	-
75	Cleaning management work time	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
76	Accessibility cleaning machines	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
77	Cleaning management room available	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
78	Cleaning management room number	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
79	Cleaning management room sink	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
80	Cleaning management room size	-	-	-	-	o	o	o	0/3	-	-	-	-	-	-	-	-
81	Number of sanitary objects	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
82	Number of soap dispensers	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
83	Number of towel dispensers	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
84	Number of hygiene bins	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
85	Number of fragrance dispensers	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
86	Number of toilet seat cleaners	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
87	Number of bins	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
88	Number of dust control mats	-	-	-	-	x	x	o	2/3	-	-	-	-	-	-	-	-
89	Cleaning management category	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
90	Cleaning management code	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
91	Service maintenance cleaning	-	-	-	-	o	o	o	0/3	-	-	-	-	-	-	-	-
92	Cleaning management method	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
93	Frequency maintenance cleaning	-	-	-	-	x	x	x	3/3	-	-	-	-	-	-	-	-
94	Total price maintenance cleaning	-	-	-	-	o	o	o	0/3	-	-	-	-	-	-	-	-
95	Unit price maintenance cleaning	-	-	-	-	o	o	o	0/3	-	-	-	-	-	-	-	-
96	Unit	-	-	-	-	-	-	-	-	x	x	o	2/3	-	-	-	-
97	ID unit	-	-	-	-	-	-	-	-	x	x	o	2/3	-	-	-	-
98	System sign	-	-	-	-	-	-	-	-	x	x	x	3/3	-	-	-	-
99	FIDS system	-	-	-	-	-	-	-	-	x	x	x	3/3	-	-	-	-
100	Status system	-	-	-	-	-	-	-	-	o	o	o	0/3	-	-	-	-
101	System description	-	-	-	-	-	-	-	-	x	x	x	3/3	-	-	-	-
102	Inventory number	-	-	-	-	-	-	-	-	x	x	x	3/3	-	-	-	-
103	SAP equipment	-	-	-	-	-	-	-	-	o	o	o	0/3	-	-	-	-
104	System dimensions	-	-	-	-	-	-	-	-	x	x	x	3/3	-	-	-	-
105	Main system key	-	-	-	-	-	-	-	-	o	o	x	1/3	-	-	-	-
106	Main system specification	-	-	-	-	-	-	-	-	o	o	x	1/3	-	-	-	-
107	Main system description	-	-	-	-	-	-	-	-	o	o	x	1/3	-	-	-	-
108	Main system designation	-	-	-	-	-	-	-	-	o	o	x	1/3	-	-	-	-
109	System type	-	-	-	-	-	-	-	-	x	x	x	3/3	x	x	x	3/3
110	Cost group DIN 276	-	-	-	-	-	-	-	-	x	x	x	3/3	-	-	-	-
111	Cost group DIN 276 description	-	-	-	-	-	-	-	-	x	x	x	3/3	-	-	-	-
112	System group	-	-	-	-	-	-	-	-	o	x	x	2/3	-	-	-	-
113	Trade key	-	-	-	-	-	-	-	-	x	x	o	2/3	-	-	-	-
114	Component key	-	-	-	-	-	-	-	-	x	x	o	2/3	-	-	-	-
115	Serial number	-	-	-	-	-	-	-	-	x	x	o	2/3	x	x	x	3/3
116	Manufacturer	-	-	-	-	-	-	-	-	x	x	x	3/3	x	x	x	3/3
117	Supplier	-	-	-	-	-	-	-	-	-	-	-	-	x	x	x	3/3
118	Model label	-	-	-	-	-	-	-	-	x	x	x	3/3	-	-	-	-
119	Notes	-	-	-	-	-	-	-	-	o	x	x	2/3	-	-	-	-

120	Year of construction	-	-	-	-	-	-	-	-	x	x	x	3/3	x	x	x	3/3
121	Month of construction	-	-	-	-	-	-	-	-	-	-	-	-	x	x	x	3/3
122	Date of commissioning	-	-	-	-	-	-	-	-	-	-	-	-	x	x	x	3/3
123	Link external documentation	-	-	-	-	-	-	-	-	x	o	x	2/3	-	-	-	-
124	Date warranty start	-	-	-	-	-	-	-	-	-	-	-	-	x	x	x	3/3
125	Date warranty end	-	-	-	-	-	-	-	-	x	x	x	3/3	x	x	x	3/3
126	Responsibility	-	-	-	-	-	-	-	-	x	x	x	3/3	x	x	x	3/3
127	Planned maintenance required	-	-	-	-	-	-	-	-	o	o	o	0/3	o	o	o	0/3
128	Engine room number	-	-	-	-	-	-	-	-	-	-	-	-	o	x	x	2/3
129	Number of stops	-	-	-	-	-	-	-	-	-	-	-	-	x	x	x	3/3
130	Number of doors	-	-	-	-	-	-	-	-	-	-	-	-	x	x	x	3/3
131	QR code	-	-	-	-	-	-	-	-	-	-	-	-	x	o	x	2/3
132	Work type code	-	-	-	-	-	-	-	-	-	-	-	-	o	o	o	0/3
133	Conveyor system type	-	-	-	-	-	-	-	-	-	-	-	-	x	x	x	3/3
134	Drive system type	-	-	-	-	-	-	-	-	-	-	-	-	x	x	x	3/3
135	Load bearing capacity	-	-	-	-	-	-	-	-	-	-	-	-	x	x	x	3/3
136	Opposing doors	-	-	-	-	-	-	-	-	-	-	-	-	x	o	x	2/3
137	Firefighter utilization	-	-	-	-	-	-	-	-	-	-	-	-	o	x	o	1/3
138	Evacuation utilization	-	-	-	-	-	-	-	-	-	-	-	-	o	x	o	1/3
139	Fire alarm system connection	-	-	-	-	-	-	-	-	-	-	-	-	x	x	x	3/3
140	Scheduled frequency EEIM	-	-	-	-	-	-	-	-	-	-	-	-	x	x	x	3/3
141	Point of contact	-	-	-	-	-	-	-	-	-	-	-	-	o	o	o	0/3
142	Contact information	-	-	-	-	-	-	-	-	-	-	-	-	o	o	o	0/3
143	Date of expert examination	-	-	-	-	-	-	-	-	-	-	-	-	o	o	o	0/3
144	Protocol expert examination	-	-	-	-	-	-	-	-	-	-	-	-	o	o	o	0/3
145	Date of inspection and maintenance	-	-	-	-	-	-	-	-	-	-	-	-	o	o	o	0/3
146	Protocol inspection and maintenance	-	-	-	-	-	-	-	-	-	-	-	-	o	o	o	0/3

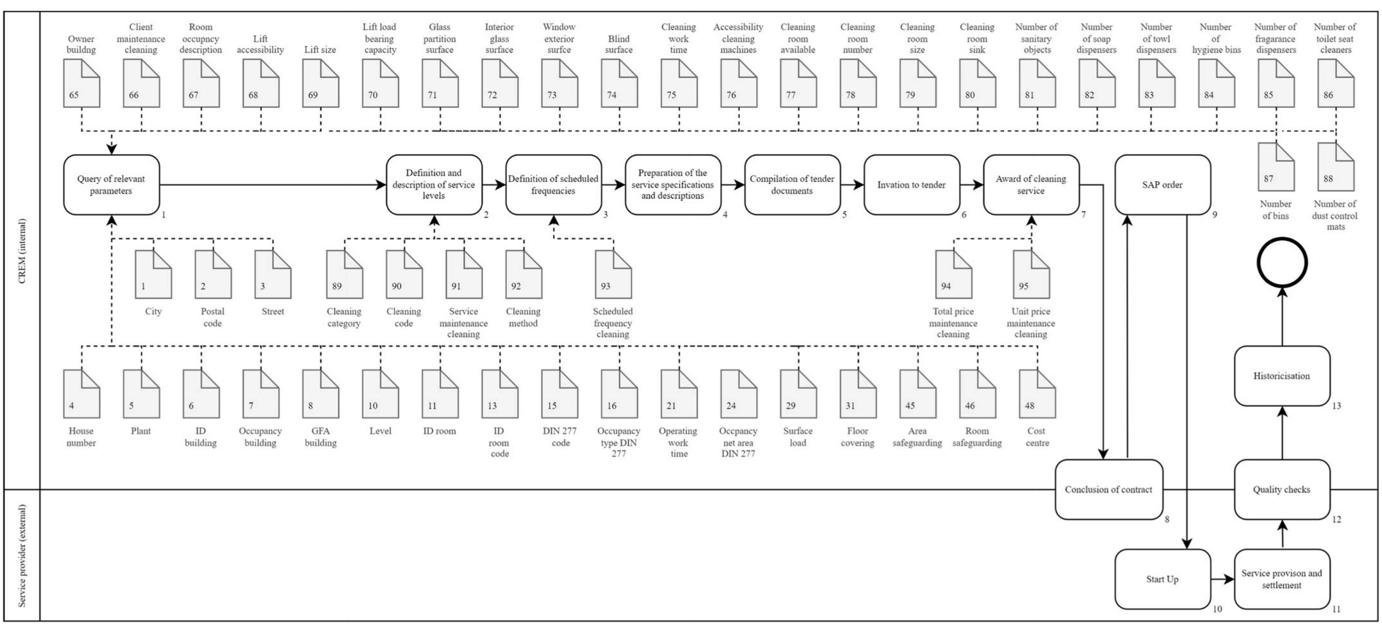

Fig. 11. Process diagram of the BIM Use “Maintenance cleaning management".

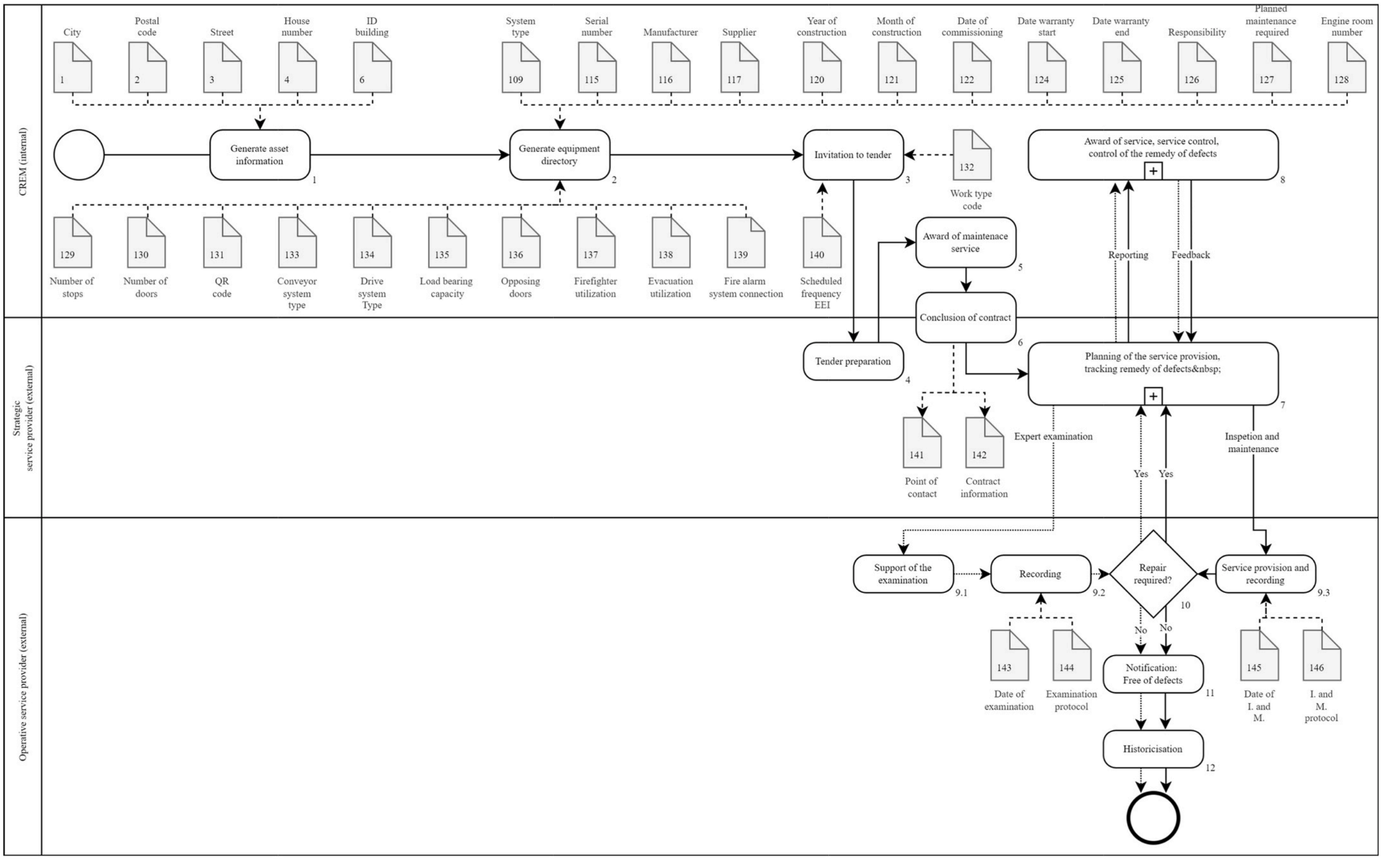

Fig. 12. Process diagram of the BIM Use “Expert examination, inspection, and maintenance of conveyor systems”.

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