Asset Information Requirement Templates for the Building Information Modelling-based Provision of Facility Services in Corporate Real Estate Management

Von der Fakultät für Architektur und Stadtplanung der Universität Stuttgart
zur Erlangung der Würde eines Doktors der
Ingenieurwissenschaften (Dr.-Ing.) genehmige Abhandlung

Vorgelegt von
Maximilian John Benn
aus Stuttgart

Hauptberichter: Prof. Dr. Christian Stoy
Mitberichter: Prof. Dr. Frank Petzold

Datum der mündlichen Prüfung: 27.02.2024

Institut für Bauökonomie der Universität Stuttgart, 2024

Asset Information Requirement Templates for the Building Information Modelling-based Provision of Facility Services in Corporate Real Estate Management

A dissertation approved by the Faculty of Architecture and Urban Planning of the University of Stuttgart for the conferral of the title of
Doctor of Engineering Sciences (Dr.-Ing.)

Submitted by
Maximilian John Benn
from Stuttgart

Committee chair: Prof. Dr. Christian Stoy
Committee member: Prof. Dr. Frank Petzold

Date of the oral examination: 27.02.2024

Institute for Construction Economics of the University of Stuttgart, 2024

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AECO	Architecture, engineering, construction, and operation
AIM	Asset information model
AIR	Asset information requirements
BDS	Building description system
BEP	BIM execution plan
BIM	Building information model
CAFM	Computer-aided facility management
CDE	Common data environment
CMMS	Computerized maintenance management system
COBie	Construction operations building information exchange
CRE	Corporate real estate
CREM	Corporate real estate management
DIN	Deutsches Institut für Normung (German Institute for norms)
DLT	Distributed ledger technology
e.g.	Exempli gratia (= Latin for "for example")
EIR	Exchange information requirements
ERP	Enterprise resource planning
FIDS	Facility identification system
FM	Facility management
GEFMA	German Facility Management Association
GLIDE	Graphical language for interactive design
IAI	International Alliance for Interoperability
i.e.	Id est (= Latin for "that is")
IFMA	International Facility Management Association
IoT	Internet of things
IR	Information requirement
ISIC	International standard industrial classification
LCC	Life cycle cost
MEP	Mechanical, electrical, and plumbing
MIDP	Master information delivery plan
OIR	Organisation information requirements
OQS	Online questionnaire survey
PIM	Project information requirements
RDS	Room data sheet
RQ	Research question
SSI	Semi-structured interview

SLR	Systematic literature review
SNA	System of National Accounts
SSOT	Single source of truth
SVIT	Schweizerischer Verband der Immobilienwirtschaft (Swiss Association of Real Estate)
TIDP	Task information delivery plan

Abstract

Building information modelling (BIM) has greatly accelerated the digitalisation of the architecture, engineering, construction, and operation (AECO) industry across all life cycle phases. Concerning the financial impact of each life cycle phase, the operational phase accounts for the majority of the life cycle cost of a building. Therefore, academic research on BIM implementation in the operational phase has been steadily increasing over the past few years. Relevant studies indicate that BIM implementation offers considerable potential for corporate real estate management (CREM), as real estate operations and maintenance constitute one of the biggest expenses for organisations in many industry sectors. However, the extent of relevant studies on BIM implementation in CREM remains limited and progresses only gradually.

The early consideration of information requirements for CREM demands extensive knowledge about the BIM method and an active involvement of all stakeholders in the early project phases. This applies all the more in the context of technically challenging buildings relying on the continuous provision of facility services. Some of the main challenges to BIM implementation in CREM are the lack of defined BIM uses for CREM, the complex definition process of asset information requirements (AIR), and the autonomous implementation of guidelines and templates.

The presented research investigated four research trajectories to address these and other research gaps. Firstly, the definition of BIM uses supporting the provision of facility services in CREM. Secondly, the identification of BIM uses with a high implementation priority across all industry sectors. Thirdly, the development of AIR templates for BIM uses for CREM with a high implementation priority and the identification of the most accurate approach to AIR template definition. Fourthly, the practical implementation of the project results through their formalisation in an AIR template implementation framework for owners and operators in CREM.

A total of 35 BIM uses for CREM were identified and defined on the basis of international documents. It became apparent that the number and content of the mentioned BIM uses varied considerably between the analysed sources. A survey among CREM experts from Austria, Germany and Switzerland was conducted to identify BIM uses with a high implementation priority across all industry sectors. Maintenance-related BIM uses generally had a high implementation priority across all industry sectors

The triangulation- and the process-based approach to the generalisation of AIR templates were identified based on relevant research and applied to four BIM uses. The accuracy of the developed AIR templates was compared in semi-structured interviews with CREM experts from three companies. In the process, the underlying approaches were evaluated regarding their suitability for the development of generalisable templates for BIM uses for CREM. To accommodate relevant research findings on the industry sector-dependence of information requirements, the application and comparison of the identified approaches was conducted in the context of the chemical industry.

In the assessments, process-based approaches provided more accurate and, therefore, more generalisable AIR templates for CREM in the chemical industry. Furthermore, it became apparent that hygiene-, safety- and maintenance-related information is of particular relevance for this industry sector.

Five recommendations for the implementation of AIR templates were derived from the results of the semi-structured interviews. They were translated into an AIR template implementation framework for owners and operators in CREM and formalised in three main stages: The customization, the selection, and the mapping of information requirements. The framework is designed as a 12-step flow chart with three lanes representing the three relevant stakeholders in AIR definition and implementation.

The presented research extends the current state of research in this field and establishes the foundation for further research directions by providing a total of four contributions. Firstly, a list of BIM uses supporting the provision of facility services in CREM was defined. Secondly, BIM uses with a high implementation priority across all industry sectors were identified. Thirdly, an accurate approach to AIR template definition was identified and the first iteration of AIR templates for four BIM uses for CREM in the chemical industry was developed. Fourthly, an AIR template implementation framework for owners and operators of CREM in the chemical industry and other industry sectors was formalised. Further research directions include studies based on the presented list of BIM uses, the definition of standardised BIM uses and AIR for CREM, and the investigation of further building use classes and industry sectors in this context.

Zusammenfassung

Building Information Modelling (BIM) hat den Digitalisierungsprozess in der gesamten Immobilienwirtschaft über alle Lebenszyklusphasen hinweg beschleunigt. Hinsichtlich der finanziellen Auswirkungen einzelner Lebenszyklusphasen macht die Betriebsphase den größten Teil der Lebenszykluskosten eines Gebäudes aus. Vor diesem Hintergrund nahm der Umfang akademischer Forschung zur BIM-Implementierung in der Betriebsphase in den letzten Jahren stetig zu. Einschlägige Arbeiten deuten darauf hin, dass die BIM-Implementierung beträchtliches Potential für das Corporate Real Estate Management (CREM) bietet, da die Nutzungskosten von Liegenschaften für Unternehmen in vielen Wirtschaftszweigen eine der größten Ausgaben darstellen. Der Umfang einschlägiger Arbeiten zur BIM-Implementierung im CREM ist allerdings nach wie vor begrenzt und nimmt nur allmählich zu.

Die frühzeitige Berücksichtigung der Informationsanforderungen des CREM erfordert umfassende Kenntnisse über die BIM-Methode sowie eine aktive Einbindung aller Stakeholder in den frühen Projektphasen. Dies gilt umso mehr im Kontext technisch anspruchsvoller Gebäude, welche auf die kontinuierliche Bereitstellung von Dienstleistungen, den sogenannten Facility Services, angewiesen sind. Einige der größten Herausforderungen für die BIM-Implementierung im CREM sind der Mangel an definierten BIM-Anwendungsfällen für das CREM, der komplexe Definitionsprozess von Liegenschaftsinformationsanforderungen (englisch: asset information requirements, kurz AIR) sowie die autonome Implementierung von Leitfäden und Vorlagen.

Die vorliegende Arbeit untersucht vier Forschungsrichtungen um diese und weitere Forschungslücken zu schließen. Erstens die Definition von BIM-Anwendungsfällen, welche die Bereitstellung von Facility Services im CREM unterstützen. Zweitens die Identifikation von BIM-Anwendungsfällen mit einer hohen Implementierungspriorität in sämtlichen Wirtschaftszweigen. Drittens die Entwicklung von AIR-Vorlagen für BIM-Anwendungsfälle mit einer hohen Implementierungspriorität und die Identifikation des präzisesten Ansatzes für die Definition von AIR-Vorlagen. Viertens die praktische Implementierung der Projektergebnisse durch deren Formalisierung in einem Konzept zur Implementierung von AIR-Vorlagen für Eigentümer und Betreiber im CREM.

Insgesamt 35 BIM-Anwendungsfälle für das CREM wurden auf Grundlage internationaler Dokumente identifiziert und definiert. Hierbei fiel auf, dass Zahl und Inhalt der genannten BIM-Anwendungsfälle teils stark zwischen den analysierten Quellen variierten. Eine Onlineumfrage unter CREM-Expert_innen aus Deutschland, Österreich und der Schweiz wurde zur Identifikation von BIM-Anwendungsfällen mit einer hohen Implementierungspriorität in allen Wirtschaftszweigen durchgeführt. Wartungsbezogene BIM-Anwendungsfälle wiesen dabei über alle Wirtschaftszweige hinweg eine hohe Umsetzungspriorität auf.

Der triangulations- und der prozessbasierte Ansatz zur Generalisierung von AIR-Vorlagen wurden auf der Grundlage einschlägiger Forschung identifiziert und auf vier BIM-

Anwendungsfälle appliziert. Die Genauigkeit der entwickelten AIR-Vorlagen wurde in semistrukturierten Interviews mit CREM-Expert_innen aus drei Unternehmen verglichen. Hierbei wurden die zugrunde liegenden Ansätze hinsichtlich ihrer Eignung für die Entwicklung generalisierbarer Vorlagen für BIM-Anwendungsfälle im CREM bewertet. Unter Berücksichtigung einschlägiger Forschungsergebnisse zum Einfluss des Wirtschaftszweigs eines Unternehmens auf seine Informationsanforderungen wurde die Anwendung und der Vergleich der identifizierten Ansätze im Kontext der chemischen Industrie durchgeführt.

In diesen Untersuchungen lieferten prozessbasierte Ansätze präzisere und damit generalisierbarere AIR-Vorlagen für das CREM in der chemischen Industrie. Darüber hinaus zeigte sich, dass hygiene-, sicherheits- und wartungsbezogene Informationen für diesen Wirtschaftszweig von besonderer Bedeutung sind.

Fünf Empfehlungen für die Implementierung von AIR-Vorlagen wurden aus den Ergebnissen der semistrukturierten Interviews abgeleitet. Diese wurden anschließend in eine Struktur zur Implementierung von AIR-Vorlagen für Eigentümer und Betreiber im CREM übersetzt und in drei Hauptstufen formalisiert: Die individuelle Anpassung, die Auswahl und das Mapping von Informationsanforderungen. Die Struktur ist definiert als ein 12-stufiges Flussdiagramm mit drei Bahnen für die drei relevanten Stakeholder bei der AIR-Definition und -Implementierung.

Die vorliegende Arbeit erweitert den Stand der Forschung auf diesem Gebiet und schafft die Grundlagen für weitere Forschungsrichtungen durch insgesamt vier Beiträge. Erstens wurde eine Liste von BIM-Anwendungsfällen definiert, welche die Bereitstellung von Facility Services im CREM unterstützen. Zweitens wurden BIM-Anwendungsfälle mit einer hohen Implementierungspriorität in allen Wirtschaftszweigen identifiziert. Drittens wurde ein präziser Ansatz für die Definition von AIR-Vorlagen identifiziert sowie die erste Iteration von AIR-Vorlagen für vier BIM-Anwendungsfälle für das CREM in der chemischen Industrie entwickelt. Viertens wurde ein Konzept zur Implementierung von AIR-Vorlagen für Eigentümer und Betreiber im CREM in der chemischen Industrie und weiteren Wirtschaftszweigen formalisiert. Weitere Forschungsrichtungen eröffnen sich durch Studien auf der Grundlage der entwickelten Liste von BIM-Anwendungsfällen, die Definition von standardisierten BIM-Anwendungsfällen und AIR für das CREM sowie die Untersuchung weiterer Gebäudenutzungen und Wirtschaftszweige in diesem Zusammenhang.

1 Introduction

1.1 Point of Departure

Digitalisation in the architecture, engineering, construction, and operation (AECO) industry finds itself at a disadvantage in comparison to most other industry sectors. In recent years, however, the advent of technologies like the internet of things (IoT), 3D scanning, and building information modelling (BIM) have greatly accelerated this process, especially in the fields of building design, construction, operation, and maintenance (European Construction Sector Observatory, 2021). Accordingly, actors like the EU BIM Task Group have identified BIM implementation as "the construction sector's moment of digitalisation" for all building life cycle phases (EU BIM Task Group, 2018, p. 8).

In this context, the potential for direct or indirect financial savings is a frequently-mentioned expected benefit of BIM implementation. Concerning the impact of each life cycle phase on the accumulated life cycle cost of a building, it is widely acknowledged that the cost of the operational phase greatly exceeds that of all other life cycle phases combined. Based on ISO 15686-5, this cost is composed of operational and maintenance costs, constituting two of the four elements of the life cycle cost (LCC) of a building (International Organisation for Standardisation, 2017a).

Estimations of the financial impact of the operational phase on the overall life cycle cost vary between 60 % (Lewis et al., 2010) and 85 % of the total life cycle cost (Scarponcini, 1996). Given this financial impact, potential cost savings through BIM implementation in the operational phase are expected to be considerable. As a result, academic research on BIM implementation in the operational phase has steadily been growing over the past few years (Edirisinghe et al., 2017).

1.2 Problem Statement

A study by Gerbert et al. (2016) estimated the cost-saving potential of BIM implementation for different building use classes. The results show that the cost-saving potential in the operational phase of industrial projects such as power stations and chemical plants or discrete manufacturing plants is estimated at between 8 % and 13 %. Given that corporate real estate management (CREM) often represents one of the largest expenses for organisations in many industry sectors, it can be assumed that CREM departments can considerably contribute to the success of an organisation by achieving cost savings through BIM implementation (Nase and Arkesteijn, 2018; Pfnür, 2014).

The BIM-based provision of facility services appears to be a suitable starting point for BIM implementation in this context. This is because BIM-based data management is expected to offer substantial efficiency gains for the provision of facility services (Wilkinson and Jupp, 2016). However, relevant research on BIM implementation in CREM remains limited and is only progressing slowly, “despite [the] disproportionate physical dominance [of corporate real estate] within most societies” (Abideen et al., 2022, p. 32). One of the most frequently identified obstacles in this context lies in the definition of information requirements for BIM uses. Munir et al. (2019) concluded that many owners and operators struggle with BIM implementation in the operational phase because of limited experience or knowledge in this field. Additionally, Cavka et al. (2017) found that some owners and operators show a general lack of awareness regarding the need for an early and comprehensive definition of information requirements before the planning and construction phases while the few existing guides for owners and operators are of limited use.

Alshorafa and Ergen (2020) state that “there is no guidance to determine what information should be included in a BIM model for different BIM uses” and that “[the] available standards require highly accumulated experience and understanding of the entire BIM use”. As a result, inaccuracies in the definition of information requirements and information capture frequently occur. This impedes BIM implementation in the context of CREM, as owners and operators often rely on generic recommendations for the definition of information requirements.

Dixit et al. (2019) suggested that further research be conducted to define templates or guides for BIM use implementation to address these obstacles. Edirisinghe et al. (2017) similarly concluded that further research on the definition and implementation of specific BIM uses in the operational phase is needed. However, relevant research also indicates that the industry sector of an organisation influences its information requirements for processes in the operational phase (Cavka et al., 2017; Munir et al., 2020). Therefore, any approach to the development of templates or guides for BIM use implementation has to accommodate the individual characteristics of the investigated industry sectors.

1.3 Research Objectives

The presented research aims to address the above-mentioned research gaps by providing BIM use-specific templates for asset information requirements (AIR) and a respective implementation framework promoting their implementation in CREM. It aims to enable owners and operators in CREM to independently identify and implement BIM uses, contributing to the process execution and provision of facility services within their respective organisations. In this context, four trajectories were defined for this research.

The first is the identification of potential BIM uses supporting the provision of facility services in CREM and the definition of these identified BIM uses to accommodate the specific context of CREM. Second is the identification of BIM uses with a high implementation priority across all industry sectors for the further development of AIR templates and the assessment of their implementation priority. Third is the definition of the AIR template for the BIM uses for CREM with a high implementation priority and the identification of the most accurate approach to AIR template definition. The fourth is the support of the practical implementation of the project results by providing an AIR template implementation framework for owners and operators in CREM.

Four research questions (RQ) have been formulated based on these research trajectories:
RQ 1: Which facility services can be supported through BIM uses in the context of CREM?
RQ 2: Which BIM uses for CREM have the highest implementation priority?
RQ 3: Which is the most accurate approach for the development of AIR templates for CREM?
RQ 4: How can the implementation of AIR templates be formalised for owners and operators in CREM?

2 Background

As the presented research concerns the investigation of BIM implementation in the context of CREM, it overlaps with a multitude of different research fields. This chapter provides an overview of the research fields constituting the background for the presented research.

2.1 Corporate Real Estate Management

CREM originated in the 1930s when the first real estate departments were established within corporations. These departments focused on the alignment of real estate to corporate needs and objectives. Their main purpose was to address the needs and wishes of shareholders and different stakeholders on strategic, tactical and operational levels.

By the 1980s, the term “corporate real estate management” had been coined and established as an academic discipline (van der Voordt, 2017). Today, CREM describes the management of the built assets owned by an organisation.

Regarding the precise delimitation of the term “corporate real estate” (CRE), Heywood and Kenley (2013) propose two possible definitions: all real estate owned by an organisation, whether core-business-related or not, or exclusively the real estate related directly to the core business of an organisation, provided that the core business is not real estate. The authors of this paper favour the latter definition as CREM represents the demand side of the real estate economy and takes a use perspective rather than an investment-ownership perspective. Glatte (2021) likewise defines CREM as core business-related.

The predominant building use classes in CREM are office, storage, production, and retail buildings (Krumm, 2001). Depending on the industry sector of an organisation, real estate and CREM can account for up to 20 % of the running costs, making it the second largest expense in many industry sectors (Pfnür, 2014). The majority of these expenses, however, do not result from capital expenditure (CAPEX) during the planning and construction phases but from operational expenditure (OPEX) during the operational phase, as illustrated in Figure 1.

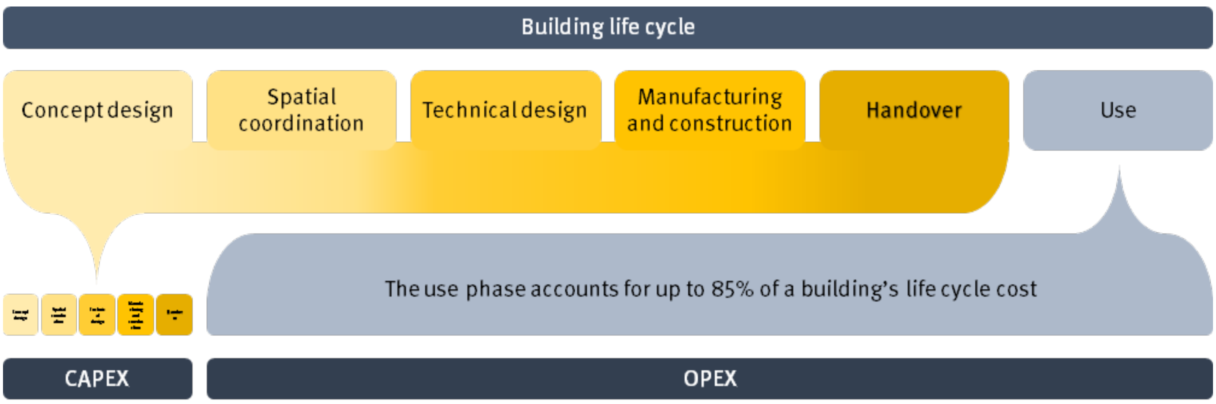


Figure 1: The financial impact of the operational phase within the building life cycle based on Lewis et al. (2010)

The OPEX of a building accounts for up to 85 % of the life cycle cost of a building, mainly resulting from operational and maintenance processes based on ISO 15686-5 (International Organisation for Standardisation, 2017a; Lewis et al., 2010). Therefore, the planning and construction phases are not the only factors to be considered when assessing the life cycle costs of CRE. Instead, cost-effectiveness and its optimisation in the operational phase as well as the identification of inefficiencies have gradually become one of the main goals of modern CREM. In so doing, CREM has gradually shifted from being considered a mere workplace provision to being viewed as a department contributing immensely to the performance of other departments and areas of a business such as human resources, finances, internal culture development, productivity, and marketing. Therefore, some argue that CREM has a strategic capability, contributing directly to the success of an organisation and ranging from the operational to the strategic level (Glatte, 2021; Omar and Heywood, 2014; van der Voordt, 2017). In this context, the alignment of CREM objectives to the strategic goals of an organisation can be achieved through improvements in productivity, property management, the handling of facilities, and reduced operating costs (Omar and Heywood, 2014). As illustrated in Figure 22, CREM includes the FM disciplines of asset management, property management, and building management. Thus, it can initiate and achieve improvements across all these management levels.

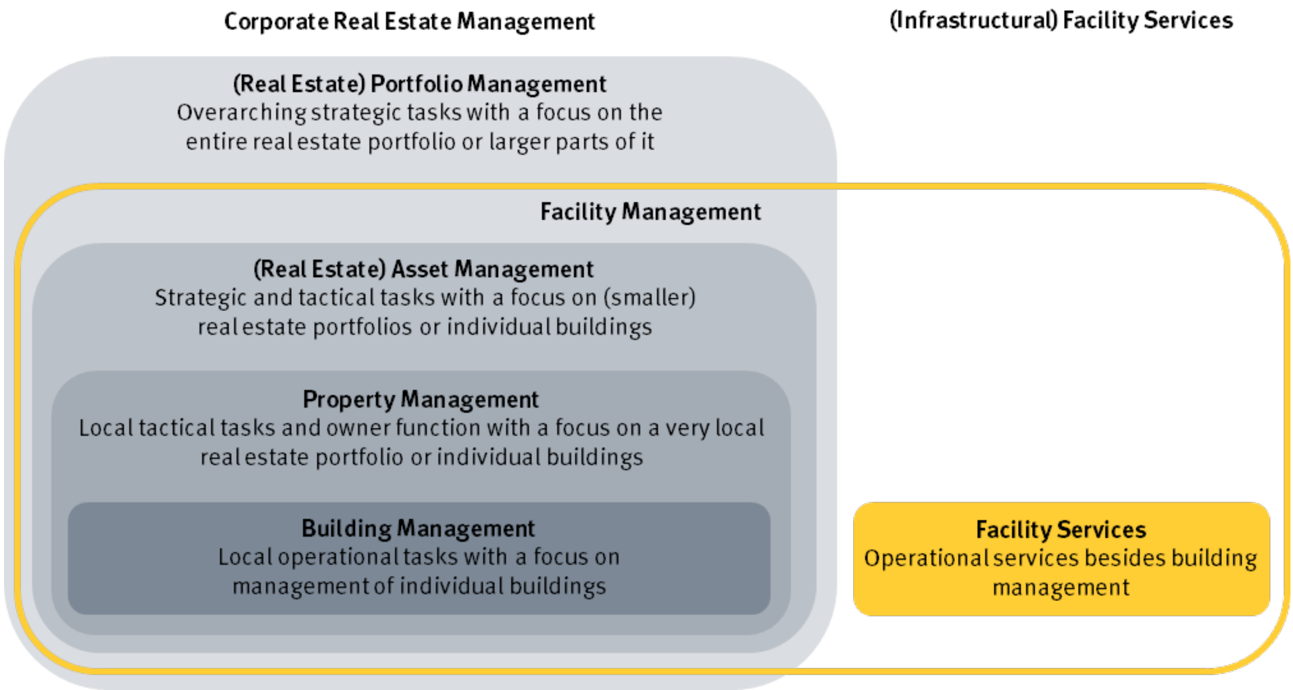


Figure 2: Disciplines of CREM and infrastructural facility services based on Glatte (2021)

Even though Glatte (2021) considers most aspects of FM to be part of CREM, the exact relationship between CREM and FM still gives rise to discussions. The relationship, similarities, and dissimilarities between CREM and FM were investigated by van der Voordt (2017). According to van der Voordt, it can be concluded that CREM and FM often have different histories, key objectives, concepts, theories and data tools. In summary, the author states that FM focuses on non-core business services and their management while CREM focuses on the integration of management disciplines and cost control. Furthermore, van der Voordt states that CREM regards real estate as an asset used for its purposes, whereas FM is service-oriented, mainly considering the fulfilment of demands related to space, infrastructure, people and organisations. Even so, a clear convergence can be observed between CREM and FM and an ever-increasing integration and alignment between the two, raising the question of future terminology.

As the exact relationship between CREM and FM remains a field of research providing ample material for discussion, this dissertation is confined to using the term CREM to describe all aspects of FM except facility services, as described by Glatte (2021).

2.2 Building Information Modelling

The term "building information model" first appeared in 1992 in a publication by van Nederveen and Tolman (1992). It described an approach to develop a model containing building information based on the individual views of different stakeholders in a construction project. The concept of BIM, however, dates back to the 1970s. Eastman et al. (1974) developed the so-called building description system (BDS), incorporating a system for entering complex shapes as well as the capability to edit and compose data, produce perspectives or orthographic drawings, and sort and format databases via attributes.

Further development of the principles defined in the BDS led to the creation of the Graphical Language for Interactive Design (GLIDE). It is considered one of the precursors to modern BIM software. Eastman and Henrion (1977) defined GLIDE as a "general language with object modelling capabilities in a database environment [...] intended to form a convenient basis for constructing a new generation of more powerful CAD applications" (Eastman and Henrion, 1977, p. 25).

Following this development, further precursors to modern BIM software evolved simultaneously in different countries. In the UK, the software RUCAPS from 1977 and its successor SONATA from 1986 are two of the most prominent forerunners of modern BIM (Port, 1989; See, 2007). At the same time, the software Radar-Ch was developed by a German-Hungarian collaboration and released in 1982 (Pavan et al., 2020). In France, the software Architrion was developed in the 1980s and released in 1989 (Pavan et al., 2020). In 2002, the term "building information modelling", as it is used today, was introduced in a whitepaper by Autodesk (2002).

ISO 19650-1 defines BIM as the "use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions" (International Organisation for Standardisation, 2018a, p. 5). Messner et al. (2019) specify that "BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition. A basic premise of BIM is the collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder" (Messner et al., 2019, p. 11).

Both definitions include three core principles of BIM: the emphasis on stakeholder collaboration and involvement, the goal to encompass the whole life cycle of a building, and the use of a shared digital representation, as illustrated in Figure 3 (Wu et al., 2020).

Figure 3: Application scope of BIM by Wu et al. (2020), licence: CC BY 3.0

By incorporating and implementing these core principles, BIM aims to overcome "silo mentalities", the late or inadequate involvement of owners or operators, as well as insufficient communication between stakeholders (Munir et al., 2019; Pärn et al., 2017; Sobhkhiz et al., 2021). However, the implementation of BIM and its core principles continues to pose a challenge to the AECO industry as they require loss-free data storage and exchange between different disciplines and life cycle phases. This challenge was addressed through the development of a common data environment (CDE) constituting an indispensable tool for the incorporation of the three core principles of BIM, as illustrated in Figure 4.

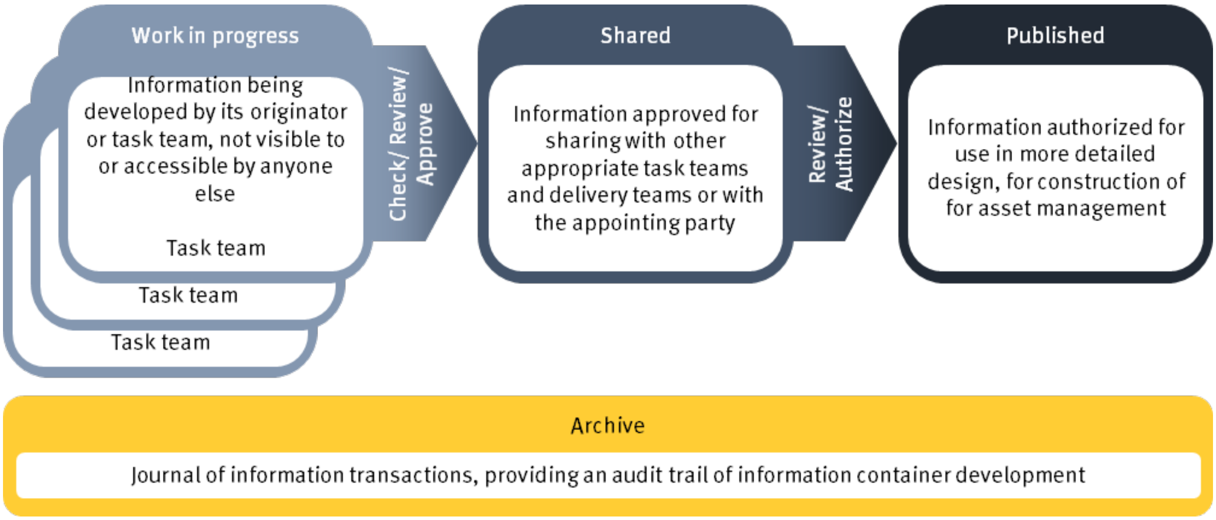


Figure 4: Common data environment (CDE) concept based on ISO 19650-1

A CDE serves as an "agreed source of information for any given project or building, for collecting, managing and disseminating each information container through a managed process" (International Organisation for Standardisation, 2018a, p. 5). To facilitate, optimise, and secure this data exchange, the BIM stored in a CDE is used as a single source of truth (SSOT).

In contrast to separated digital representations for different disciplines, a CDE aims to establish efficient and transparent information flows of reliable and up-to-date data between all stakeholders. However, the above-mentioned variety of BIM software poses an obstacle to the concept of a CDE, as the data exchange between different software tools remains chronically prone to error (Dixit et al., 2019). To address this challenge, the International Alliance for Interoperability (IAI) was founded in 1994 and renamed "buildingSMART" in the early 2000s. It aims to develop a platform-neutral, open data schema specification to facilitate data model exchange within the AECO industry. As a result, the industry foundation classes (IFC) were defined to promote interoperability and loss-free data exchange between different software for object-oriented building models (Bazjanac and Crawley, 1997). To further enhance interoperability and compatibility, IFC defines multiple formats for different application scenarios, as shown in Table 1. Today, the STEP Physical File format is the most commonly used IFC format.

Table 1: Current IFC formats based on buildingSMART Technical Services (2023)

Format	Extension	Size
STEP Physical File (SPF)	.ifc	100 %
Extensible Markup Language (XML)	.ifcXML	113 %
ZIP	.ifcZIP	17 %
Terse RDF Triple Language (Turtle)	.ttl based on ifcOWL	1372 %
Resource Description Framework (RDF/XML)	.rdf based on ifcOWL	816 %
JavaScript Object Notation (JSON)	.json	148 %
Hierarchical Data Format (HDF)	.hdf	n/a

2.3 Asset Information Requirements for Facility Services

As illustrated in Figure 2, facility services stand apart in the field of facility management. 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, 2017b, p. 1).

On a European level, EN 15221-4 describes and classifies facility services, including the activities, facilities, and processes necessary for their provision (Comité Européen de Normalisation, 2011). It further specifies that the main task of any facility management department is to effectively support the main activities of an organisation and to add value to the client organisation. This can be achieved through the coordinated provision of individual facility services.

Individual facility services are considered individual processes, composed of various standardised facility services or facility products. The standardised facility services or facility products are categorised into several hierarchically structured and classified processes. To define an individual facility service, “standardized [facility services or facility products] defined [EN 15221-4] can be combined to ‘individual’ facility services provided to the customers” (Comité Européen de Normalisation, 2011, p. 80).

In Germany, the GEFMA 100-2 guideline provides a widely-used catalogue of FM main processes and corresponding FM processes for all life cycle phases. For the operational phase, GEFMA 100-2 defines a total of nine FM main processes and their corresponding FM processes (German Facility Management Association e.V., 2004). Despite the divergent terminology, these FM main processes and corresponding FM processes are, in most parts, equivalent to the standardized facility services or facility products defined in EN 15221-4.

The research presented in this paper uses the term “facility service” to describe the “standardised facility services or facility products” based on EN 15221-4 and the “FM processes” based on GEFMA 100-2. Facility services constitute the basis for most processes in facility management and, as a consequence, in CREM. Therefore, the alignment of facility services to the main activity of an organisation is an essential goal of CREM. To fully harness the potential of BIM in CREM, the information needed for the provision of a facility service has to be translated into BIM-based deliverables to be subsequently defined as information requirements.

When initiating a project, owners and operators can order their information requirements and integrate them into the project-specific AIR. Based on ISO 19650-1, “[the] AIR set out managerial, commercial and technical aspects of producing asset information”. Furthermore, “[the] technical aspects of the AIR specify those detailed pieces of information needed to answer the asset-related [organisational information requirements] (OIR)” (International Organisation for Standardisation, 2018a, p. 10). The OIR constitute the fundamental information requirements defined by the appointing party or client “to meet the needs of its organisational functions and its asset management system” (International Organisation for Standardisation, 2020, p. 14). Both the AIR and the OIR are integrated into the exchange information requirements (EIR), "[setting] out managerial, commercial and technical aspects of producing project information" (International Organisation for Standardisation, 2018a, p. 10).

After defining the OIR, AIR, PIR, and EIR, a BIM execution plan (BEP) can be developed. This document defines how information management and exchanges should be conducted. After its confirmation, the responsibility matrix, task information delivery plan(s) (TIDP), master information delivery plan (MIDP), and appointment documents are specified, as defined in ISO 19560-2 (International Organisation for Standardisation, 2018b). Figure 5 illustrates this information requirement progression from the OIR to the BEP and, eventually, into the AIM.

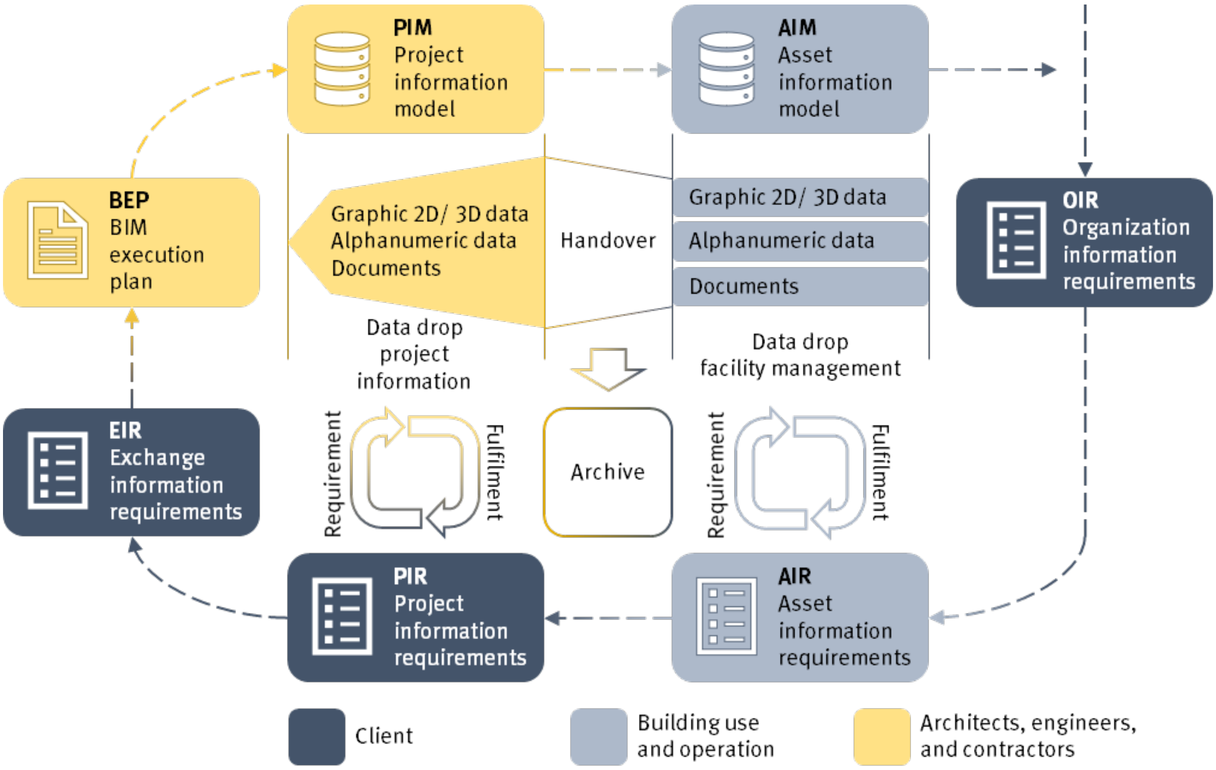


Figure 5: BIM execution model based on Bauen digital Schweiz/ buildingSMART Switzerland (2020)

Based on the BEP, TIDP, and MIDP, the architects, engineers, and contractors are then obliged to add the information requirements for their respective discipline to the project information model (PIM). In the further course of the project, they are responsible for updating their respective information requirements during the planning and construction phases until the handover of the asset information model (AIM). However, the above-mentioned lack of templates or guides hampers the definition of AIR for facility services in CREM. To address this research gap, several studies have investigated the definition and development of AIR templates in this context.

Mayo and Issa (2016) identified an absence of guiding documents for owners and operators. The authors suggested that the definition of information requirement templates for owners and operators be investigated in further research. Ashworth et al. (2017) state that research on information requirements for the operational phase was scarce. The authors concluded that owners and operators are often confronted with extensive information requirements when tackling BIM-based projects. Therefore, the authors suggested that further research on templates or guides regarding predefined information requirements be conducted.

Cavka et al. (2017) based their study on the observation that BIM implementation in the operational phase is hampered by a lack of knowledge regarding BIM-based information requirements for the provision of facility services. To address this research gap, the authors aimed to establish a systematic approach to the definition of information requirements. The authors concluded that the industry sector of an organisation strongly influences its information requirements for the operational phase, impeding the generalisation of the defined information requirements across all industry sectors.

Munir et al. (2019) state that owners and operators can be overwhelmed by the amount of potentially significant information requirements for the operational phase. This renders the identification of truly necessary information requirements a time-consuming and laborious task. To address this obstacle, the authors aimed to define sets of mandatory key information requirements for the operational phase. The authors also found that the information requirements of an organisation are influenced by its industry sector, hampering the global generalisability of the defined information requirement templates. In conclusion, the development of structured yet customisable guides for BIM implementation in the operational phase was suggested.

Dixit et al. (2019) based their study on the observation that research on BIM implementation in the operational phase was still highly limited. The authors aimed to identify the key challenges of BIM implementation in the operational phase to derive further research directions and potential solutions. In conclusion, the authors suggested that further research be conducted to develop documents defining BIM uses for the operational phase.

Alshorafa and Ergen (2020) identified an absence of guiding documents on BIM implementation for owners and operators. In conclusion, the authors suggested further research on precisely defined BIM uses, their process descriptions, and information requirements to support stakeholders with limited BIM experience.

2.4 BIM uses

The early consideration of all life cycle phases is indispensable for the successful implementation of the BIM method. Given the complexity of today’s construction projects, the simultaneous consideration of the construction, handover, operational, renovation, and demolition phases requires considerable expertise and far-sightedness. In response to this complexity and the resulting information requirements, the concept of BIM uses was developed to facilitate the structuring of information requirements. The buildingSMART Alliance defines a BIM use as “a method or strategy of applying [BIM] during a facility's life cycle to achieve one or more specific objectives" (buildingSMART Alliance, 2013, p. 5).

Based on this concept, a BIM use typically consists of three parts, as illustrated in Figure 6. These are the BIM use definition, the process description, and the information requirements. The initial BIM use definition elaborates not only on its description but also on its benefits, goals, basics and delimitations from other BIM uses. The achievement of these benefits and goals through BIM uses is a core concept of BIM implementation. As BIM aims to encompass the entire building life cycle, a considerable quantity of BIM uses for different processes in different life cycle phases has been identified by national and international organisations.

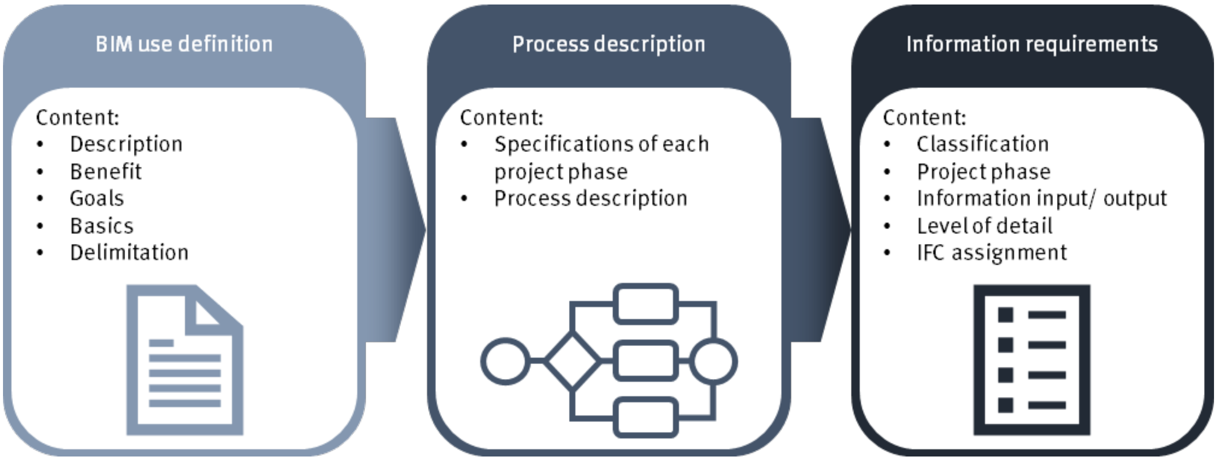


Figure 6: The concept of BIM uses based on Bauen digital Schweiz/ buildingSMART Switzerland (2019)

This abundance of interdependent BIM uses, often serving as input and output for each other across life cycle phases and stakeholders, requires the early identification and definition of all relevant BIM uses and their interdependencies, as illustrated in Figure 7. As mentioned above, all relevant BIM uses need to be identified during the project initiation "beginning with the end in mind" to include their information requirements in the EIR (Messner et al., 2019, p. 28). As Figure 7 illustrates, BIM uses for the operational phase often rely on the output from BIM uses from the planning and construction phases.

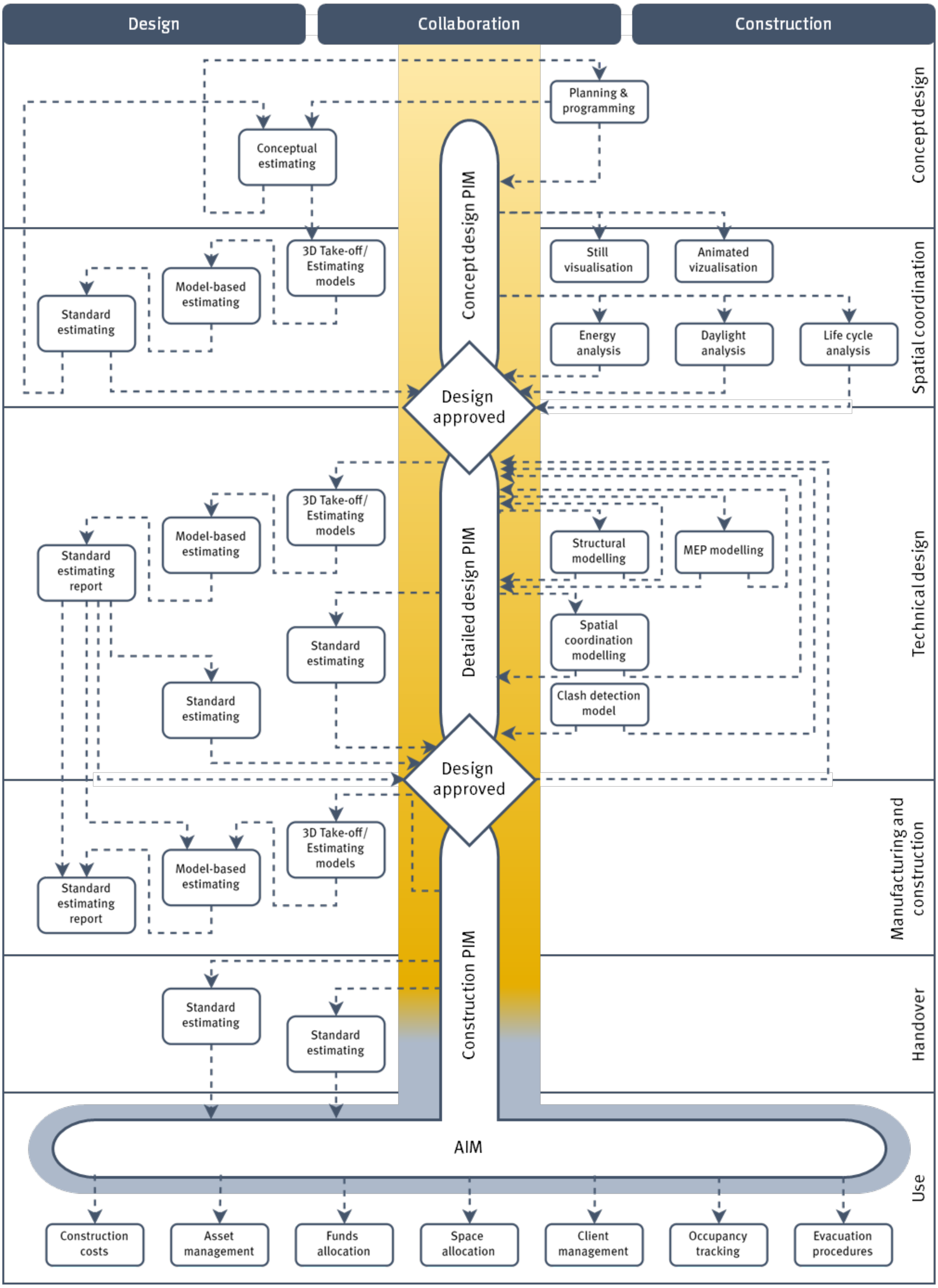


Figure 7: BIM uses and their interdependencies throughout the life cycle phases of a building based on Joseph (2011)

As research on BIM implementation in the operational phase progresses, the identification and definition of BIM uses in this context are investigated. However, studies focusing specifically on CREM and its unique requirements are rare and the identified information requirements are rarely linked to specific BIM uses. Despite the limited research on BIM uses for CREM, two studies investigating his field of research could be identified.

Lazar and McArthur (2016) developed a data visualisation application of BIM to connect decentralised systems in CREM. The authors investigated three BIM uses in their case study: space management, complaints visualisation, and equipment maintenance. The results showed that the key benefit of BIM lies within its function as a central hub for information exchange between different platforms. In conclusion, the authors suggested that further research should further investigate the application of BIM as a visualisation tool and as an information exchange hub.

Carbonari et al. (2018) investigated which tasks in FM and CREM are prone to inefficiencies to identify BIM application areas in this context. The authors mapped the perceived inefficiency of tasks against the number of IFC entities necessary for their execution. The results showed that the tasks benefiting most from BIM implementation are asset records, the analysis of maintenance data, satisfaction surveys, the evaluation of business performance, and post-occupancy evaluation. In addition to these research results, several characteristics are to be considered when identifying and defining BIM uses in the context of CREM. CREM portfolios are often large and diverse, comprising a variety of sometimes highly complex buildings (Carbonari et al., 2018).

This makes CREM an intriguing field of BIM implementation as it offers a considerable number of starting points for the implementation of BIM uses. However, information management itself can be a considerable cost factor in CREM, as the operation of technically complex and diverse buildings often involves large amounts of heterogeneous data (Wilkinson and Jupp, 2016). Thus, selecting multiple BIM uses and ordering the respective information bears the risk of adding workload but no appropriate value if conducted without prior evaluation of the realistic benefit. In light of these characteristics, the selection of BIM uses should be conducted carefully and in direct correspondence with the objectives and information management processes of an organisation. Furthermore, any AIR templates in this context should aim to be as concise as possible to avoid unnecessary information management workload.

Finally, related research also indicates that the industry sector of an organisation influences its information requirements, as mentioned above (Cavka et al., 2017; Munir et al., 2020). Thus, it is plausible to assume that AIR templates for BIM uses for CREM may only be generalisable to a certain extent.

3 Methodology

As relevant research on BIM implementation in CREM remains limited, the amount of available quantitative and qualitative data is likewise restricted. Therefore, an exploratory approach was adopted for this paper. This chapter provides an overview of the research methods adopted during the research.

3.1 Literature review

3.1.1 Systematic Literature Review

Literature reviews are an integral part of academic research as they lay the groundwork for "making scholarly knowledge accessible, identifying gaps in this knowledge, determining research questions for empirical research and informing evidence-based interventions, policies, practices and treatments" (Dekkers et al., 2022, p. xiii). In the context of empirical studies, literature reviews mainly serve two purposes. Firstly, the identification of scholarly knowledge and the explanation of how the investigation is going to build on it. Secondly, the development and justification of the adopted study design and data collection methods. Therefore, literature reviews need to provide five results:

- The identification of research gaps and the assessment of their relation to the topic of the research
- The consolidation of the identified scholarly knowledge
- The conceptualisation of the identified constructs, perspectives, and variables
- The overview of how the identified scholarly knowledge is related to the applied methods
- The development of potential limitations and expedient countermeasures for the research.

An initial obstacle to conducting SLR, however, is the fact that it is often unknown which sources should be identified and how they can be procured. Even if a precise idea of the required sources exists, they are likely to be highly diverse, e.g. scientific papers, essays, newspaper articles, reviews, or book chapters, and distributed over various sources, e.g. bibliographic databases of journals or publishers or library catalogues. Additionally, sources are often indexed differently, e.g. by keywords, short summaries, or highlights (Dekkers et al., 2022; Franke et al., 2014). To address these obstacles, a ten-step process is applied in this paper and refined during repeated application to identify, collect, analyse, and synthesize sources, as illustrated in Figure 8.

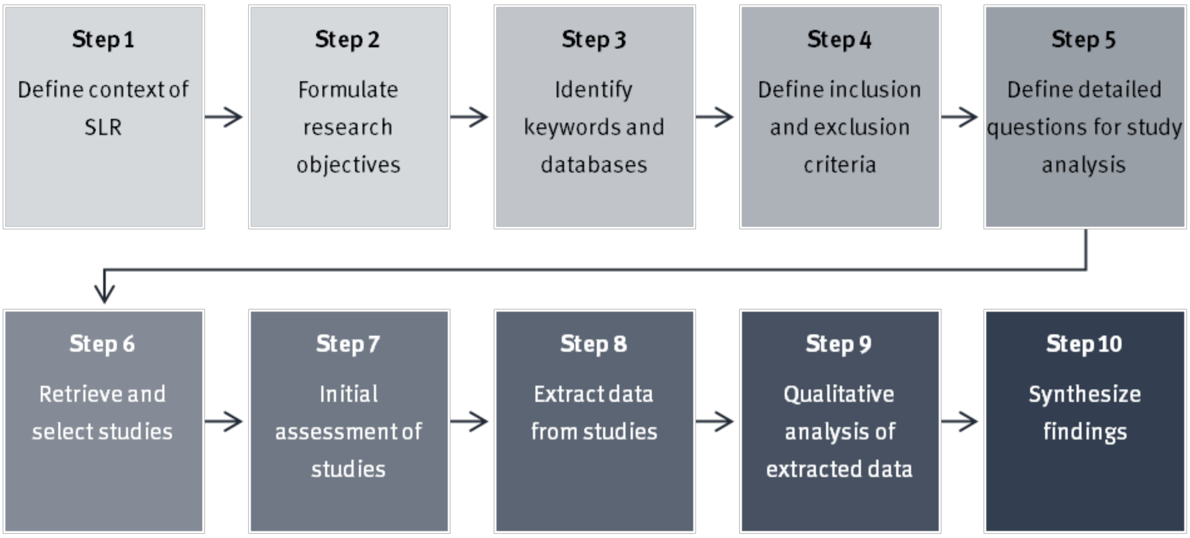


Figure 8: Process for an SLR for qualitative synthesis based on Dekkers et al. (2022)

3.1.2 Snowball System

Alongside the SLR, the "snowball system" was applied. The snowball system is an unsystematic form of literature search often applied as a supplement to systematic research methods. When analysing relevant sources, the sources cited within them are also evaluated. If further sources are identified that are yet unknown but potentially relevant, they are obtained and the cited sources within them are evaluated in turn. Inclusion and exclusion criteria are applied based on the adopted systematic literature review process or research protocol. This process offers two major benefits. Firstly, it allows the identification of sources that were not covered by systematic research methods. Secondly, repeated application without the identification of unknown literature indicates that the vast majority of relevant sources have been identified and considered (Cardoso Ermel et al., 2021; Dekkers et al., 2022).

3.2 Online Questionnaire Survey

Online questionnaire surveys (OQS) are a widespread internet-based tool for data collection based on the application of online surveying tools and questionnaires. The questionnaires are usually made accessible on the server of a university, research institute or other provider. Potential participants receive links directing them to the surveying tools where they are asked to fill out the questionnaires. The choice of whether OQS are an appropriate tool for data collection must be made carefully. Thus, the advantages and disadvantages of alternative survey methods should be weighed against those of OQS.

At first glance, OQS have several advantages over telephone surveys, face-to-face interviews, and written-postal surveys. Firstly, they are time-independent and space-independent, allowing all potential respondents to be simultaneously contacted regardless of long distances. This counteracts undesirable methodological effects that may occur due to different survey times and locations. Secondly, OQS easily allow the integration of new, graphically sophisticated instruments. Interactive questionnaire elements such as sliders or drag-and-drop as well as multimedia content such as pictures, audio elements or videos can be integrated without much effort. These tools can motivate participants and help to clarify questions (Homburg et al., 2022; Sarstedt and Mooi, 2019). However, OQS also have certain disadvantages. The most obvious disadvantage is the fact that the actual qualification and eligibility of a participant for a survey are difficult and sometimes impossible to gauge. Additionally, OQS face obstacles when it comes to motivating the accessible population to participate. Internet users, especially experts in high positions, are often harassed by mass mailings or other inquiries, some of them with a commercial interest (Homburg et al., 2022; Stockemer, 2019; Wagner-Schelewsky and Hering, 2019). Measures to address these disadvantages include the distribution of OQS through specialist platforms, the inclusion of questions on the participants professional background and experience, and so-called "snowball sampling" relying on the further distribution of the OQS by verified experts.

3.3 Cronbach's Alpha

Cronbach's alpha (also Cronbach's α, rho-equivalent reliability, or coefficient alpha) is a measure of the internal consistency of a group of questions within a questionnaire. When calculating Cronbach's alpha, a group of questions is called a scale and each question in that group is called an item. Cronbach's alpha is a measure of the internal consistency of a scale, i.e. the extent to which the items in a scale are related to each other. This allows an estimate of how high the reliability, i.e. the measurement accuracy of that scale, is. The standardized Cronbach's alpha is calculated using the formula:

$$\alpha = \frac{k\bar{c}}{\bar{v} + (k-1) * \bar{c}}$$

Where k represents the number of items, $\bar{v}$ the average variance, and $\bar{c}$ the average inter-item covariance. It expresses the internal consistency of a scale by taking values between 0 (low internal consistency) and 1 (very high internal consistency). The higher the internal consistency of a questionnaire is, the closer Cronbach's alpha is to the value 1. As mentioned above, the internal consistency allows the reliability of a scale to be estimated indicating how accurately a test can measure a variable. Therefore, a high Cronbach's alpha indicates that the observed scale measures the included variables with high accuracy (Sarstedt and Mooi, 2019; Taber, 2018).

3.4 Eta Coefficient

The eta coefficient or η (the small Greek eta) is a measure that can be used to describe the relationship between a nominal and a metric variable. Karl Pearson, who first published this measure in 1905, initially called it the correlation ratio. Later, it became known as the correlation index or η-coefficient (Pearson, 1905). It makes it possible "to measure the strength of a nonlinear or curvilinear association; in other words, it is a test for correlation between a categorical and a scale variable. Because categorical data by its nature cannot exist in a truly linear relationship with scale data, we cannot use the typical measure of linear association, Pearson's Correlation Coefficient. However, the eta Coefficient can test for correlation in curvilinear or nonlinear relationships" (Scott Jones, 2019, p. 2). This means that the eta coefficient can be calculated as a measure of the relationship between two variables, of which the dependent (Y) variable has the measurement level of an interval or ratio scale, while the independent (X) variable can have any measurement level, i.e. also that of a nominal scale.

Examples of what the eta coefficient can be calculated for are employment status (X) and monthly income from work (Y), religious denomination (X) and frequency of certain religious activities (Y). It is always possible to reduce a ratio or interval scale to an ordinal or nominal scale to calculate a coefficient expressing the relationship between the variables. The eta coefficient is calculated using the formula:

$$\eta = \frac{\frac{1}{n-1} \times \sum_j^k \times n_j \, (\bar{y}_j - \bar{y})^2}{s_y^2}$$

n represents the number of items, $\bar{y}$ represents the mean value of the variable, and s_y signifies the variance of $\bar{y}$. It expresses the strength of the relationship between the two variables by taking values between 0 (no association) and 1 (strong association). The interpretation of the eta coefficients can be conducted based on Pearson's correlation coefficient, as shown in Table 2.

Table 2: Pearson's correlation coefficient for the interpretation of the eta coefficient

Pearson's Correlation Coefficient	**Interpretation**
0.00	No association between the two variables
0.01 – 0.19	No or negligible association between the variables
0.20 – 0.39	Weak association between the variables
0.40 – 0.69	Medium association between the variables
0.70 – 1.00	Strong association between the variables

3.5 Semi-structured Interviews

The semi-structured interview (SSI) is an interview method among the qualitative, open forms of data collection. It is a form of questioning which, along with content analysis and observation, is one of the three basic methods of empirical social and communication research. It can be defined as a form of data collection using the interview guides as an instrument to collect verbal data (Loosen, 2015). It is partially structured through an interview guide determining the questions and their order for the interview.

In contrast to strictly structured interviews, the SSI allows some freedom and does not script the entire interaction between the interviewer and the interviewee. Thus, the SSI aims to find a balance between the desired openness of interview situations and the necessary structure to assure the comparability of the findings. This can be accomplished by developing an interview guide outlining the questions and their sequence but allowing the interviewer to dig deeper or the interviewee to elaborate further on certain questions.

Consequently, the SSI offers several advantages including a high information gain, a certain degree of flexibility, a clear structure, and comparably easy application even for less experienced interviewers. However, the SSI also has certain disadvantages. The preparation and execution of an SSI can be time-consuming and the comparison of the results also requires considerable work and diligence, making data collection and evaluation more difficult than highly structured or quantitative methods (Sarstedt and Mooi, 2019; Yin, 2016). Measures to address these disadvantages include the limitation of open questions and the early development of detailed evaluation and analysis techniques.

3.6 Information Requirement Generalisation

Regarding the definition of generalisable AIR templates, various approaches can be discerned. The Deutsches Institut für Normung e.V. (2021) published a “BIM Standardisation Roadmap” recommending that standards be developed to define the scope and content of different BIM uses in different life cycle phases. However, precise information requirements or implementation procedures are excluded from this recommendation. In contrast, buildingSMART International (2023) has adopted a more detailed approach. Its “Use Case Management” platform defines operational processes as well as information requirements for different BIM uses in different life cycle phases based on the IDM (Information Delivery Manual) methodology.

The BIMe initiative (2023) proposes a third approach: the so-called “Model Use Templates”. Despite still being under development, its stated aim is to define extended definitions, software tools, and activity flow diagrams for different BIM uses in different life cycle phases. On the one hand, the above-mentioned concepts illustrate a certain diversity of approaches for the definition of AIR templates for BIM uses. On the other hand, they are indicative of a fundamental disagreement on how and to which extent AIR templates for BIM uses should be defined and structured. Nonetheless, the development of AIR templates for BIM uses requires the generalisation of information requirements based on an accurate approach. Based on the above-mentioned concepts and related research, two approaches to the generalisation of information requirements have been identified. Both approaches are discussed in the following sections.

3.6.1 Method 1: Triangulation

The triangulation of information requirements is the first approach to the generalisation of information requirements. The triangulation method is defined by the consideration of a research object from three or more perspectives. Relevant research often applies this approach when multiple sources for the definition of information requirements are available. Based on Flick (2018), this approach requires the inclusion of multiple investigators, theories, methods, data sources, or perspectives to increase the reliability of the research results. Therefore, data source triangulation was selected as the first approach to the generalisation of information requirements.

3.6.2 Method 2: Process Diagrams

Process diagrams are another frequently adopted approach for the definition of information requirements in relevant literature. Due to its definition of distinct process steps, it is particularly suitable for clearly defined and delimited activities. Regarding the generalisation of information requirements for BIM uses, process diagrams are also recommended by buildingSMART International (2023) as they align with the process, interaction, and transaction maps defined in ISO 29481-1 (International Organisation for Standardisation, 2016). Therefore, the definition of process diagrams was selected as the second approach to the generalisation of information requirements.

3.7 Fleiss' Kappa

Fleiss' kappa (κ) is a statistical measure of the inter-rater reliability of assessments by three or more raters. To apply Fleiss' kappa, the measured variable must be a nominal variable. This means that its values represent categories that cannot be ranked naturally or measured using an interval or ratio scale. A typical example of this statistical measure is whether three psychologists or doctors agree on their diagnoses regarding the same patients. The inter-rater reliability based on Fleiss' kappa was calculated using the following formulas:

1. $\kappa = \frac{\bar{P}-\overline{P_e}}{1-\overline{P_e}}$
2. $p_j = \frac{1}{Nn}\sum_{j=1}^{N} n_{ij}\,, 1 = \sum_{j=1}^{k} p_j$

3. $P_i = \frac{1}{n(n-1)}$
4. $\bar{P} = \frac{1}{N}\sum_{i=1}^{N} P_i$
5. $\bar{P_e} = \frac{1}{N}\sum_{j=1}^{N} p_j^2$

$\bar{P}$ represents the mean of the $P_i's$ and $\bar{P_e}$; P_i signifies the extent to which raters agree on the i[th] subject; $\bar{P_e}$ represents the hypothetical probability of chance agreement; p_j signifies the proportion of all assignments which were to the j[th] category; N represents the total number of subjects; n signifies the number of ratings per subject; k represents the number of categories into which assignments are made; i signifies the subjects; j represents the categories of the scale; n_{ij} signifies the number of raters who assigned the i[th] subject to the j[th] category.

Fleiss' kappa expresses the strength of agreement between the raters by taking values between 0 (poor agreement) and 1 (almost perfect agreement). The specific interpretation of Fleiss' kappa can be conducted based on Landis and Koch (1977), as shown in Table 3.

Table 3: 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

4 Results

The presented research concerns the investigation of four research trajectories to enable owners and operators in CREM to independently identify and implement BIM uses contributing to the process execution and provision of facility services within their respective organisations. Article 1 and 2 in the appendix elaborate on how the following research trajectories were investigated:

- The first research trajectory aimed to identify and define BIM uses for CREM based on national and international guides as well as relevant research. The goals were to provide a comprehensive, scientifically sound list of existing and potential BIM uses supporting the provision of facility services in CREM and a starting point for the second trajectory. Firstly, relevant national and international guides were identified. Secondly, the identified sources were analysed and compared to GEFMA 100-2 to identify BIM uses supporting the provision of facility services. Thirdly, relevant research on BIM uses in the specific context of CREM was identified to formulate CREM-specific definitions of the identified BIM uses. This research trajectory was investigated in Article 1 in the appendix.
- The second research trajectory aimed to assess the implementation priority of the identified and defined BIM uses for CREM. The goal was to provide an expert-based prioritisation for the AIR template definition. Firstly, the potential benefit of each BIM use for CREM was assessed by CREM experts. Secondly, the association between the overall benefit assessment of each BIM use and the respondents' respective industry sectors was calculated. Thirdly, the implementation priority of the BIM uses for CREM was assessed. This research trajectory was investigated in Article 1 in the appendix.
- The third research trajectory aimed to define AIR templates for the BIM uses for CREM with a high implementation priority as well as to identify the most accurate approach for AIR template definition. The goals were to identify an accurate approach for AIR template definition, provide the first iteration of AIR templates for the selected BIM uses for CREM, and provide a starting point for the fourth trajectory. Firstly, approaches to AIR template definition were identified and applied to four BIM uses for CREM. Secondly, the interrater reliability of the AIR templates was assessed to identify the more accurate of the two approaches. Thirdly, reasons for the elimination of information requirements from the AIR templates were collected. This research trajectory was investigated in Article 2 in the appendix.
- The fourth research trajectory aimed to develop an AIR template implementation framework for owners and operators in CREM. The goal was to support the independent implementation of the developed AIR templates in the planning, construction and operational phases in CREM. Firstly, recommendations for the implementation of AIR templates in CREM were derived from the previously collected reasons for the elimination of infor-

mation requirements. Secondly, the recommendations were translated into an AIR template implementation framework for owners and operators in CREM. This research trajectory was investigated in Article 2 in the appendix.

This chapter provides an overview of the results obtained from the research trajectories described above based on Article 1 and 2 in the appendix.

4.1 Identification of BIM uses for CREM

The first research trajectory aimed to identify and define BIM uses which support the provision of facility services in CREM based on national and international guides as well as relevant research. The goals were to provide a comprehensive, scientifically sound list of existing and potential BIM uses which support the provision of facility services in CREM and a starting point for the second trajectory.

Article 1 in the appendix elaborates on the study design and the adopted methodology for this research trajectory. The list of FM processes provided by the GEFMA 100-2 was used as a baseline for the identification and compilation of these BIM uses (German Facility Management Association e.V., 2004). GEFMA 100-2 defines nine FM main processes and their corresponding FM processes for the operational phase. Out of these nine FM main processes, eight were included in the scope of the presented research. FM main process number nine was considered to be a construction-related process as it covers refurbishment projects during the operational phase.

During the first systematic literature review, relevant national and international guides on BIM implementation from countries with high BIM maturity levels were identified. As a result, a total of 14 guides were identified. A comparative analysis of the FM processes defined in GEFMA 100-2 and the national and international guides resulted in the identification of 34 BIM uses for the operational phase. Subsequent validation of the list resulted in the addition of one further BIM use: “Cleaning Management: Outdoor Facilities Cleaning”.

During a second systematic literature review in combination with a snowball system, relevant research on BIM uses in the specific context of CREM was identified. As a result, a total of 8 scientific publications were identified. A comparative analysis of the identified BIM uses for the operational phase and the identified relevant research was then conducted to formulate CREM-specific definitions of all 35 BIM uses. Table 4 shows the identified BIM uses for CREM, their definitions, and the frequency references in the analysed sources.

Table 4: FM main process (FM m. p.), the number and title of the identified BIM uses for CREM, their definition, and the frequency of references in the analysed sources (Freq.)

FM m.p.	No.	BIM use	Definition	Freq.
1 Commissioning	11	Handover and Commissioning	Entering data into a PIM during design and construction based on the implemented BIM uses; Entering data into an existing AIM based on the implemented BIM uses; Entering data into an AIM based on the implemented BIM uses	10
	12	As-Built Modelling and Documentation	Model-based identification of defects during legal and technical checking; Model-based tracking and elimination of defects; Entering warranty periods into an AIM; Model-based creation of handover documents	15
2 Manage Operations	21	Visualisation	Model-based visualisations through animations and renderings; Navigation through the AIM through augmented and virtual reality	11
	22	Safety and Contingency Management	Model-based planning and coordination of evacuations and evacuation drills; Model-based verification of compliance with relevant regulations; Model-based development of emergency and rescue concepts; Derivation of plans and visualisations for the safety management	13
	23	Wayfinding and Tracking	Model-based localisation of assets and facilities; Model-based data exchange between geographic information systems and the AIM	8
	24	Derivation of 2D Plans and 3D Details	Maintenance and updating of the operational documentation; Derivation of floor plans, sections and views; Derivation of area and volume reports; Derivation of functional diagrams	16
	25	FM Management And Maintenance Documentation	Integration of the FM documentation from the AIM into CAFM systems and higher-level models; Model-based maintenance and updating of FM documentation; Derivation of the CAFM documentation	19
	26	Ticket Management	Model-based receiving of malfunction, damage and hazard reports; Digital recording and creation of orders; Model-based tracking of the elimination, resubmission or escalation of defects; Model-based reporting, measurement, and analysis	5
	27	FM Quality Management	Model-based assessment of tenant and customer satisfaction; Localisation of complaints in the AIM; Model-based analysis and improvement	1

	28	FM Sustainability and Environmental Protection	Model-based creation of environmental performance evaluations according to sustainability criteria; Model-based creation of documents and data for sustainability certifications	11
3 Provide Workplaces	31	Space and Room Management	Derivation of room data sheets; Derivation, maintenance and updating of occupancy and vacancy rates in the AIM; Model-based space analysis and controlling; Model-based space demand planning, assessment, and verification; Model-based occupancy and vacancy planning and simulation of variants	17
	32	Relocation Management	Model-based planning and coordination of relocations; Model-based documentation of relocation requirements; Derivation of visualisations and animations for decision-making	3
	33	Equipment and Furnishing	Model-based requirements assessment and procurement of furniture and workplace equipment; Model-based requirements assessment and procurement of IT equipment and IT terminals; Model-based management of furniture, workplace equipment, IT equipment, and IT terminals	4
4 Operations	41	BIM 2 Field	Information transfer from the AIM to digital layout tools; Model-based on-site consistency and quality checks; Model-based localisation of assets and facilities; Model-based application of technologies like laser scanning, 360-degree photos, and drone aerial surveys	5
	42	Structural Health Monitoring	Model-based identification and tracking of structural deformations like cracks or settlements; Derivation of reports and analyses of structural deformations	8
	43	Facility Identification System	Model-based identification of technical building services and installations; Maintenance and updating of the facility identification system in the AIM; Maintenance and updating of the spatial allocation in the AIM; Maintenance and updating of component- and asset-specific attributes in the AIM	5
	44	Facilities and Equipment: Periodic Inspections	Model-based planning and coordination of expert examinations; Model-based planning and coordination of expert examination cycles; Maintenance and updating of the documentation of expert examinations in the AIM	11
	45	Facilities and Equipment: Inspection and Maintenance	Model-based planning and coordination of inspection and maintenance; Model-based planning and coordination of inspection and maintenance cycles; Maintenance and updating of the documentation of inspection and maintenance in the AIM	19

	46	Facilities and Equipment: Repair and Renewal	Model-based planning and coordination of repair and renewal; Model-based planning and coordination of repair and renewal cycles; Maintenance and updating of the documentation of repair and renewal in the AIM	19
5 Supply and Disposal	51	Real-time Acquisition and Display of Sensor Data	Model-based collection and evaluation of real-time data for condition assessment; Model-based analysis of target-performance comparison	6
	52	Energy Management	Model-based energy efficiency assessments; Model-based simulations and evaluations for operational optimisations; Model-based monitoring of energy consumption and other building performance indicators	17
	53	Waste Management	Model-based planning and coordination of waste management; Model-based creation of waste management simulations; Derivation of waste management concepts	3
6 Cleaning and Maintaining	61	Cleaning Management: Maintenance Cleaning	Model-based planning and coordination of maintenance cleaning; Derivation of relevant quantities; Derivation of surface materials; Derivation of cleaning cycles	7
	62	Cleaning Management: Glass and Facade Cleaning	Model-based planning and coordination of glass and facade cleaning, interior and exterior; Derivation of relevant quantities; Derivation of surface materials; Derivation of cleaning cycles	7
	63	Cleaning Management: Outdoor Facilities Cleaning	Model-based planning and coordination of outdoor facilities cleaning; Model-based planning and coordination of summer and winter services; Derivation of relevant quantities; Derivation of surface materials; Derivation of cleaning cycles	-
7 Asset Management	71	Security Management	Model-based identification and evaluation of security perimeters; Derivation of plans and visualisations for the security management	6
	72	Locking Management	Model-based identification of keys and access cards for specific security perimeters; Model-based coordination and management of keys and access cards	6
	73	Rent Management	Model-based rent management; Model-based management of rent contracts; Model-based service charge settlement	5
	74	Derivation of Inventory, Component, and Equipment Lists	Model-based management of equipment and inventory lists; Derivation of technical building services and installation lists; Derivation of window, door and component lists; Derivation of machine and tool lists	13

	75	FM Accounting and FM Controlling	Derivation of key performance indicators for strategic property management; Model-based financial impact assessments of planned projects; Model-based decision-making based on financial impact assessments; Model-based development of life cycle cost prognoses	14
	76	Contract and Insurance Management	Model-based planning and coordination of services; Model-based contract management; Model-based reporting of claims to insurance companies and tracking of claim settlements	7
	77	Defect Management	Model-based tracking of warranty periods; Model-based recording and localisation of defects; Model-based communication of defects; Model-based coordination and documentation of defect rectification	7
8 Provide Support	81	Room Booking Systems	Model-based services for room booking; Model-based services for workstation booking	5
	82	Event Planning	Model-based development of event concepts; Model-based simulation and analysis of event-specific evacuation scenarios; Derivation of visualisations and animations for events	1
	83	Procurement	Model-based requirements assessment and procurement; Model-based management of resources	8

Regarding RQ 1, the investigation shows that a total of 35 FM processes defined in GEFMA 100-2 can be supported through BIM uses for CREM. Regarding the frequency of references to each BIM use in the analysed sources, it becomes apparent that most documents consider the BIM uses "Facilities and Equipment: Inspection and Maintenance" and "Facilities and Equipment: Repair and Renewal" suitable areas for BIM implementation in the operational phase. In contrast, the BIM uses "Event Planning" and "FM Quality Management" appear to be of little relevance. Furthermore, none of the identified BIM uses was mentioned in all of the analysed sources.

As mentioned above, the BIM use "Cleaning Management: Outdoor Facilities Cleaning" currently seems to be of no relevance as it was mentioned in none of the analysed sources. It should be noted that not all of the above-mentioned BIM uses have already been implemented in construction projects. However, the fact that they appear in national and international guides as well as relevant research indicates that the implementation of the identified BIM uses is at least theoretically discussed and that they are expected to yield benefits for owners and operators in the operational phase in general and in CREM in particular.

4.2 High-priority BIM uses for CREM

The second research trajectory aimed to assess the implementation priority of the identified and defined BIM uses for CREM. The goal was to provide an expert-based prioritisation for the AIR template definition.

Article 1 in the appendix elaborates on the study design and the adopted methodology for this research trajectory. To collect the necessary data for this research trajectory, an online questionnaire was conducted among 37 CREM experts from Austria, Germany, and Switzerland. The respondents were initially asked to state their position within their organisation as well as their professional background, i.e. their industry sector, based on the NACE Rev. 2 classification by the European Commission (2008). Subsequently, they were asked to assess the expected benefit of each of the identified BIM uses for CREM from 1 (very low benefit) to 5 (very high benefit). The internal consistency of the survey results was assessed based on Cronbach's alpha. Data description and analysis were then conducted in four steps.

Firstly, the arithmetic mean of all benefit assessments was calculated for each BIM use to determine its overall benefit assessment. Secondly, the association between the overall benefit assessment of each BIM use and the respondents' industry sectors was determined based on the eta coefficient. Thirdly, the eta coefficient was interpreted based on Pearson's correlation coefficient. Fourthly, the overall benefit assessment of each BIM use was displayed as a function of its eta coefficient.

Figure 9 displays the benefit assessment of each BIM use on the y-axis and the association of this assessment to the respondents' industry sectors on the x-axis. As shown in Table 2, an eta coefficient of ≥ 0.7 denotes a strong association, values between 0.4 and 0.69 denote a medium association, and values between 0.2 and 0.39 denote a weak association between the variables. Therefore, BIM uses scoring a low eta coefficient show a weak association between their overall benefit assessment and the respondents' industry sectors. This means that a low eta coefficient indicates that the BIM use's benefit assessment can be expected to remain valid across most industry sectors. This is the case for the BIM uses "Facility Identification System", "Defect Management", "Event Planning", and "Perform Procurement". In contrast, BIM uses scoring a high eta coefficient show a strong association between their overall benefit assessment and the respondents' industry sectors. This means that the BIM use's benefit assessment can be expected to be of limited validity for other industry sectors. This is the case for the BIM uses "Handover and Commissioning", "Visualisation", "FM Documentation: Management and Maintenance", and "Space and Room Management".

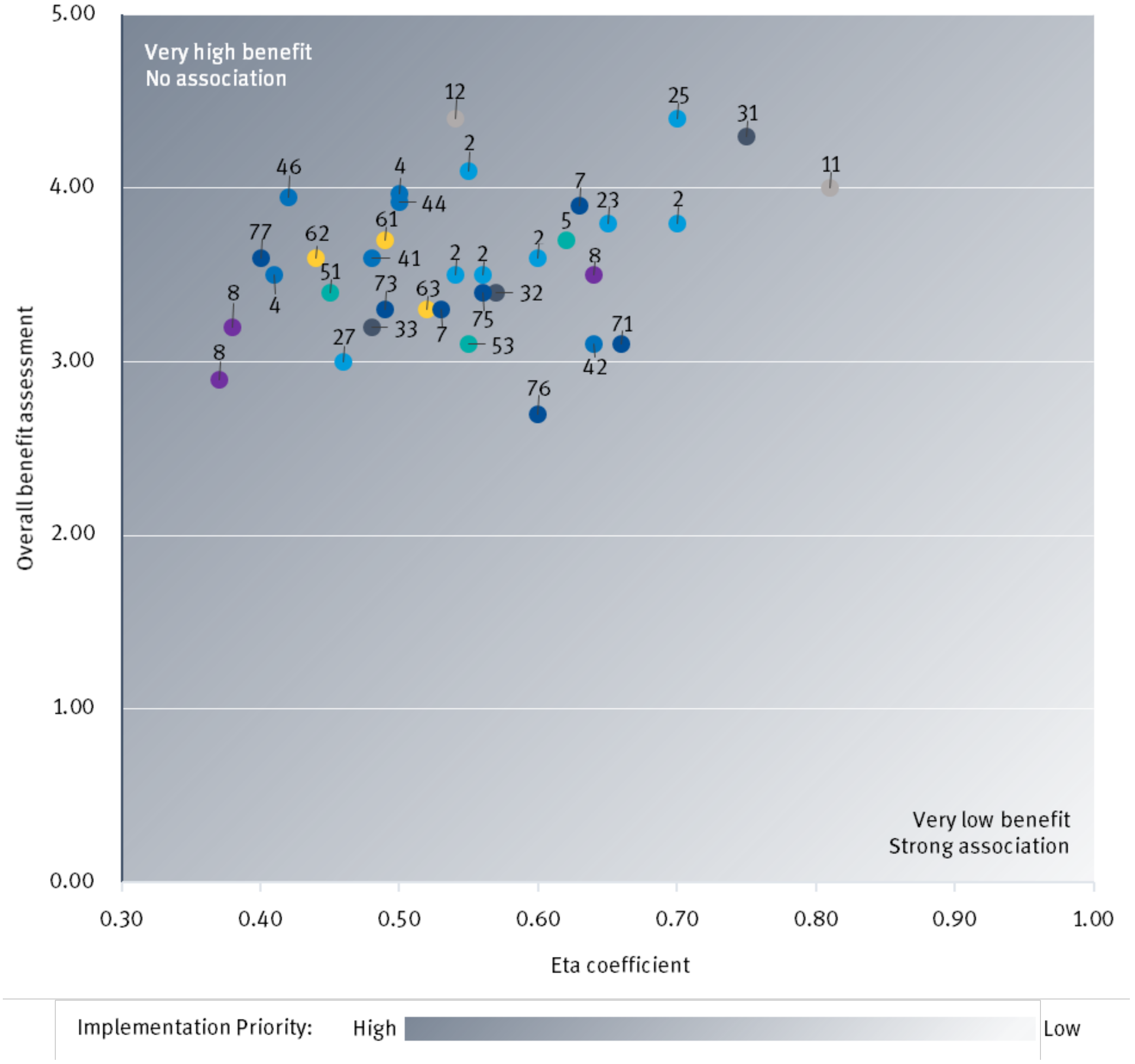


Figure 9: Overall benefit assessment of each BIM use as a function of its eta coefficient

Subsequently, the weighted product score of the respective overall benefit assessment and the eta correlation coefficient of each BIM use was calculated. This allowed the identification of BIM uses with a high overall benefit assessment and a low association of its benefit assessment to the respondents' industry sectors. Such BIM uses were identified as having a high implementation priority as their implementation would benefit multiple industry sectors. Figure 10 shows the implementation priority of the investigated BIM uses for CREM based on their weighted product score.

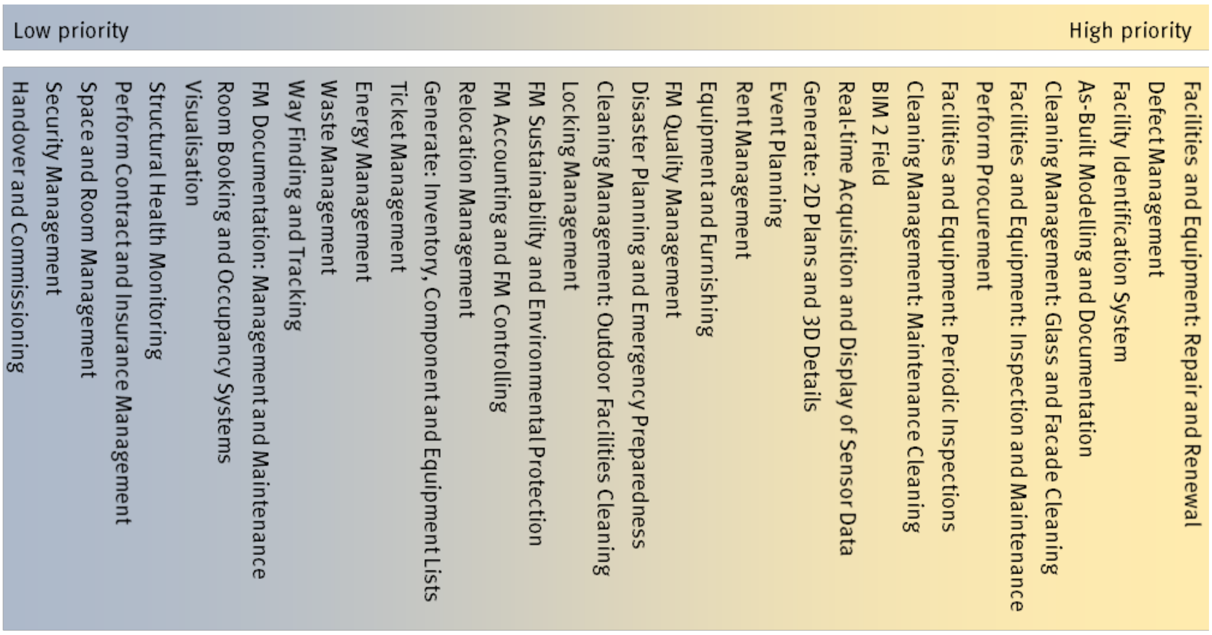


Figure 10: Implementation priority of the investigated BIM uses for CREM

Regarding RQ 2, the results show that the BIM use with the highest implementation priority is "Facilities and Equipment: Repair and Renewal" and that the BIM use with the lowest implementation priority is "Visualisation". Based on these results, four further implications were derived to outline the course of action for the subsequent research trajectories. The following implications were derived:

- Existing projects and documents should be integrated into the development of AIR templates for BIM uses in CREM
- AIR templates should define concise, yet comprehensive information requirements as a basis for organisation-specific customisation
- Technical requirements and interfaces as well as data formats should be considered when defining AIR templates
- Processes and personnel activities should be considered when defining the implementation of AIR templates in CREM

4.3 AIR templates for CREM

The third research trajectory aimed to define AIR templates for the BIM uses for CREM with a high implementation priority, identify the most accurate approach to AIR template definition and provide a starting point for the fourth trajectory.

Article 2 in the appendix elaborates on the study design and the adopted methodology for this research trajectory. Different approaches to AIR template definition were initially identified based on a systematic literature review. Two approaches to AIR template definition were identified: the triangulation-based approach and the process-based approach. As both approaches had frequently been applied in relevant research, the identification of the more accurate approach to AIR template definition in the context of CREM was the aim of this paper.

Each approach was applied to define two AIR templates, resulting in a total of four AIR templates for four BIM uses for CREM with a high implementation priority. As relevant research has identified the industry sector-dependence of information requirements, the chemical industry was selected as context for this research trajectory.

Triangulation-based AIR templates were defined for the BIM uses “Space and Room Management” and “Facility Identification System for Technical Building Services” based on the room data sheet (RDS) and the facility identification system (FIDS) conventions from three chemical industry organisations.

Process-based AIR templates were defined for the BIM uses “Expert Examination, Inspection, and Maintenance of Conveyor Systems” and “Maintenance Cleaning Management” based on relevant research identified during a systematic literature review on these BIM uses.
Subsequently, two semi-structured interviews were conducted to approve or reject the defined information requirements in the AIR templates. These interviews were conducted with 11 CREM experts from the three chemical industry organisations. The first interview investigated the space-related BIM uses “Space and Room Management”, and “Maintenance Cleaning Management”. The second interview investigated the MEP-related BIM uses “Facility Identification System for Technical Building Services” and “Expert Examination, Inspection, and Maintenance of Conveyor Systems”.

Based on the results of the first interview, the degrees of accordance of the AIR templates for space-related BIM uses were assessed, as illustrated in Figure 11.

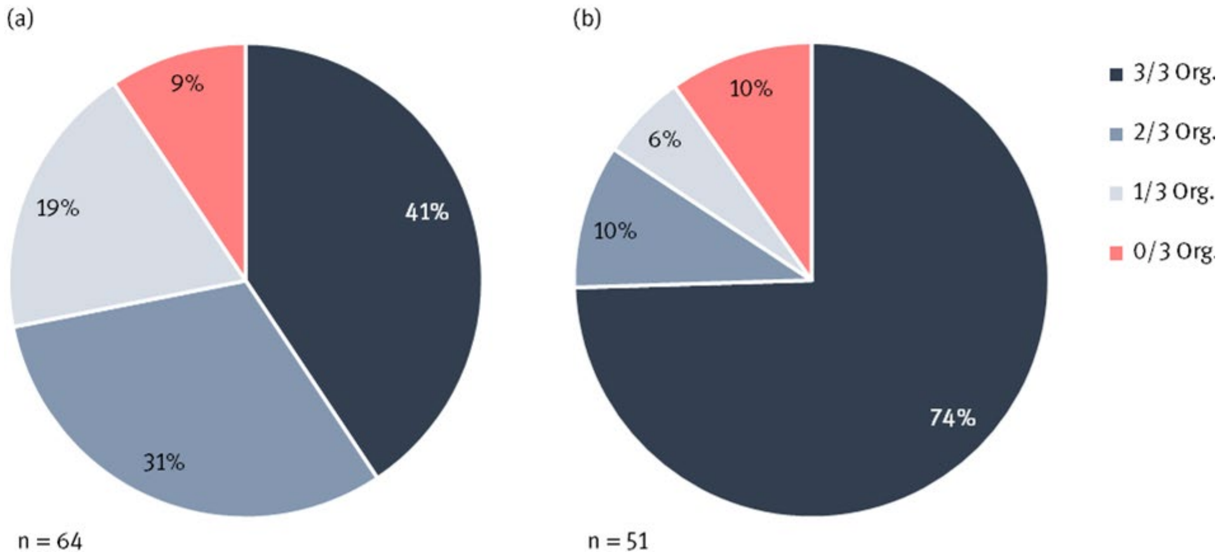


Figure 11: Degrees of accordance of the AIR templates for (a) “Space and Room Management” and (b) “Maintenance Cleaning Management”

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.

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, specific cleaning methods, and cleaning frequencies.

Based on the results of the second interview, the degrees of accordance of the AIR templates for MEP-related BIM uses were assessed, as illustrated in Figure 12.

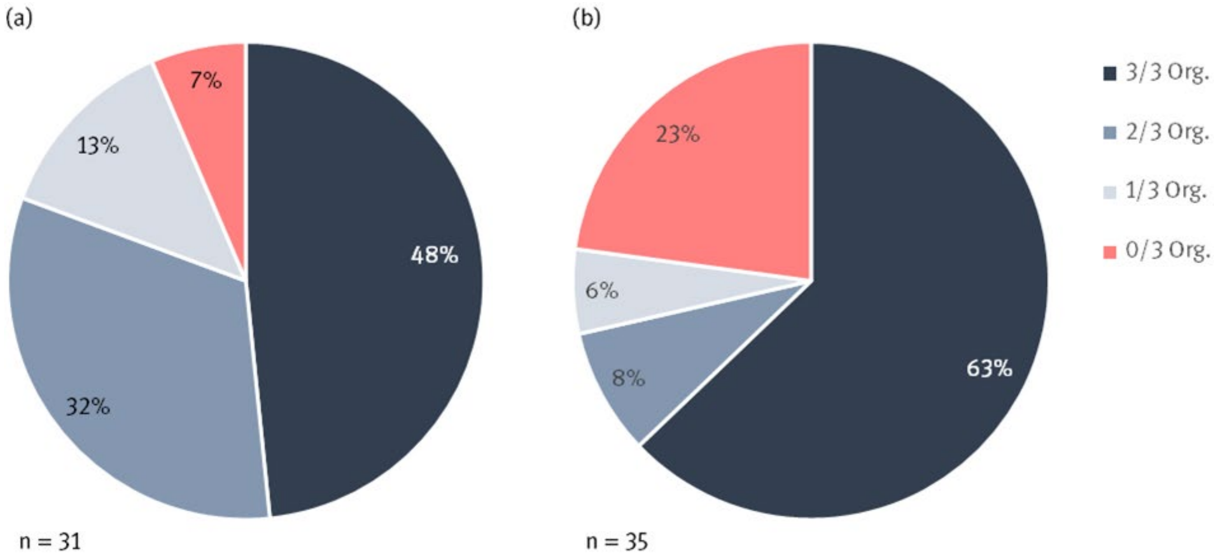
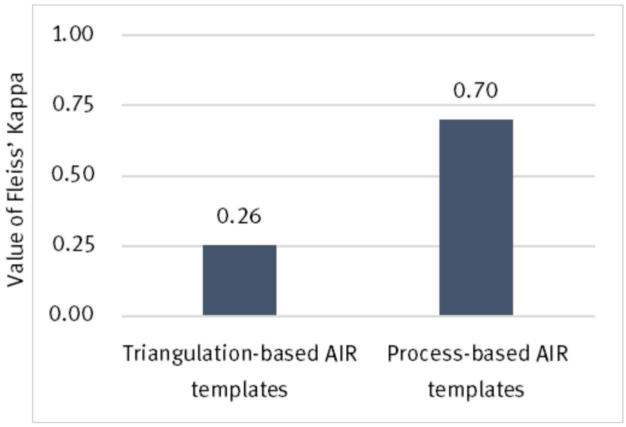


Figure 12: Degrees of accordance of the AIR templates for (a) “Facility Identification System for Technical Building Services” and (b) “Expert Examination, Inspection, and Maintenance of Conveyor Systems”

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.

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.

The accuracy of all four AIR templates was subsequently assessed based on their respective inter-rater reliability. Therefore, the Fleiss’ kappa was calculated for all four AIR templates based on the experts’ approval or rejection of the defined information requirements. The identification of the most accurate approach to AIR template definition was conducted by comparing the Fleiss’ kappa of the triangulation-based AIR templates with that of the process-based AIR templates, as illustrated in Figure 13 (a). The Fleiss’ kappa of both approaches was subsequently interpreted based on Landis and Koch (1977), as illustrated in Figure 13 (b).



(a)

Value of Fleiss’ Kappa	Strength of agreement
< 0.00	Poor
0.01 – 0.20	Fair
0.21 – 0.40	Slight
0.41 – 0.60	Moderate
0.61 – 0.80	Substantial
0.81 – 1.00	Almost Perfect

(b)

Figure 13: (a) The Fleiss’ kappa of the triangulation-based and the process-based AIR templates and (b) the interpretation of the Fleiss’ kappa based on Landis and Koch (1977)

The interpretation of both measures shows that process-based AIR templates attain “substantial” agreement whereas triangulation-based AIR templates only attain “slight” agreement.

Regarding RQ 3, the results show that the process-based AIR templates score a considerably higher strength of agreement than the triangulation-based AIR templates among the interviewed CREM experts. This finding suggests that the process-based approach is the more accurate approach for the AIR template definition as CREM experts from different organisations substantially agree on the defined information requirements.

The fourth research trajectory aimed to develop and formalise an AIR template implementation framework for owners and operators in CREM. Therefore, reasons for the rejection of information requirements defined in the AIR templates were collected. These reasons were then converted into recommendations for the implementation of AIR templates in CREM.

To collect reasons for the rejection of information requirements, each CREM expert was asked to provide a reason for the rejection of each information requirement defined in an AIR template. When an information requirement was eliminated by all three organisations, three answers were collected. Figure 14 shows the results of this survey.

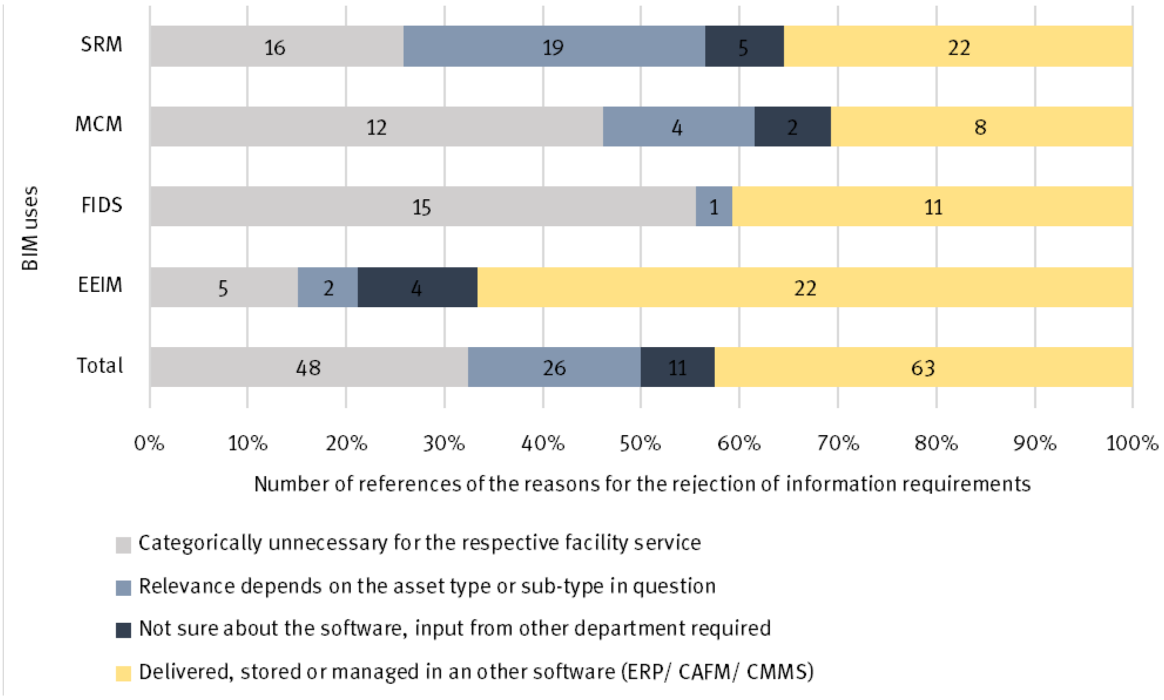


Figure 14: References to the reasons for the elimination of information requirements in proportion, based on the AIR templates for the BIM uses “Space and Room Management” (SRM); “Maintenance Cleaning Management” (MCM); “Facility Identification System for Technical Building Services” (FIDS); “Expert Examination, Inspection, and Maintenance of Conveyor Systems” (EEIM); and total references (Total)

Based on the collected reasons, the following recommendations for the implementation of AIR templates in CREM have been derived:

- The software for the delivery, storage or management of each information requirement should be identified in advance
- Static data should be prioritised when defining AIR templates
- AIR templates require customisation before implementation
- The specific asset type or sub-type of the asset in question should be defined in advance
- Stakeholders from all relevant CREM departments should be involved in the customisation and implementation process

4.4 AIR Template Implementation Framework

The fourth research trajectory aimed to develop an AIR template implementation framework for owners and operators in CREM. The goal was to support the independent implementation of the developed AIR templates in the planning, construction and operational phases in CREM. Article 2 in the appendix elaborates on the study design and the adopted methodology for this research trajectory. Initially, the previously-derived recommendations for the implementation of AIR templates for CREM were translated into a three-stage structure:

- 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.
- 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.
- 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. This step allows the final creation of BIM use- and asset (sub-) type-specific AIR.

Subsequently, this three-stage structure was translated into an AIR template implementation framework for owners and operators in CREM. Regarding RQ 4, the results shows that a total of 12 steps are necessary to implement AIR templates in CREM and to address each of the five recommendations for their implementation.

Figure 15 shows the developed framework, defining and describing each step and document necessary to convert an AIR template into customised AIR in the specific context of an organisation. The 12-step framework is designed as a vertical flow chart with three lanes, representing the three relevant stakeholders in AIR definition and customisation. These are the internal CREM department (left lane), the internal or external BIM manager (middle lane), and the external designers and contractors responsible for the creation and delivery of the BIM use-specific information requirements (right lane). By adopting an owner-operator-centric approach, the framework provides a cornerstone for BIM implementation in CREM. Furthermore, it illustrates which aspects need to be taken into consideration to successfully adopt, customise, and implement AIR templates in CREM.

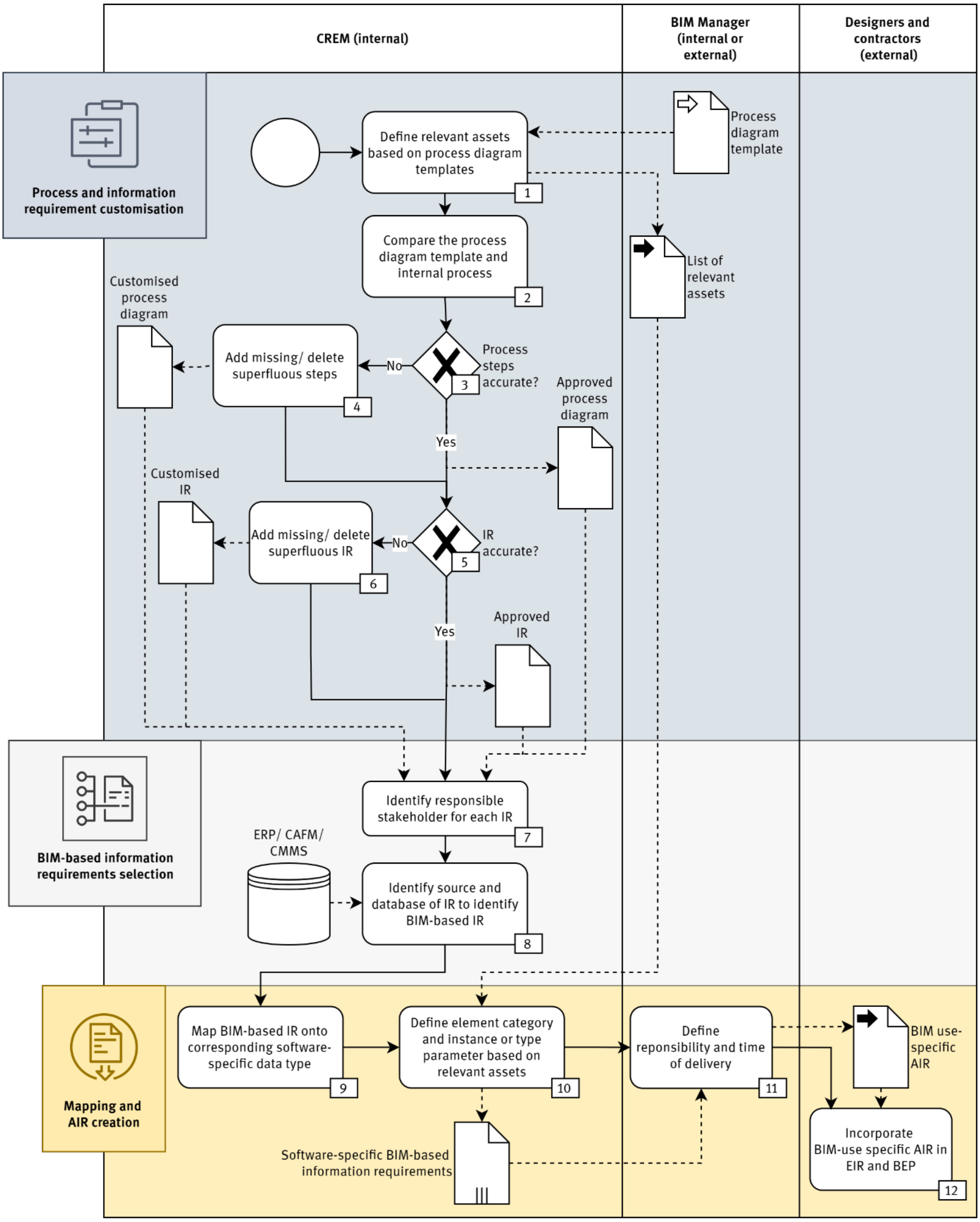


Figure 15: AIR template implementation framework for owners and operators in CREM based on process diagrams

5 Discussion and Limitations

The presented research investigated four research trajectories. Firstly, BIM uses for CREM were identified and defined. Secondly, their implementation priorities were assessed. Thirdly, the AIR template for the BIM uses for CREM with a high implementation priority were defined, and the most accurate approach to AIR template definition was identified. Fourthly, an AIR template implementation framework was developed for owners and operators in CREM. This section contextualises and discusses the presented results.

The first research trajectory included the identification and definition of BIM uses supporting the provision of facility services in CREM based on national and international guides as well as relevant literature, as shown in Table 4. It showed that nearly all FM processes defined in the GEFMA 100-2 (German Facility Management Association e.V., 2004) can be supported through a specific BIM use. These results concur with Becerik-Gerber et al. (2012), who concluded that the operational phase can considerably benefit from BIM implementation and that a multitude of processes can be supported through BIM. However, Becerik-Gerber et al. identified and investigated a comparatively limited number of BIM uses. The research in this paper further extends the state of research in this context by increasing the number of identified and defined BIM uses.

In the specific context of CREM, the presented results confirm the findings of Wilkinson and Jupp (2016), suggesting that BIM can support a wide range of processes in CREM because of its capabilities as a data delivery and management tool. Regarding the frequency of references to each BIM use, Table 4 shows that none of the identified BIM uses for CREM were mentioned in any of the analysed sources. This indicates some disagreement among academic research as well as national and international organisations regarding the processes that can or should be supported through BIM. This observation concurs with the findings of McArthur and Sun (2015), who concluded that only a fraction of the BIM uses identified in national or university guides are also mentioned in current BEP templates. One potential explanation for this observation might be that different countries have different priorities regarding the implementation of BIM uses for the operational phase. However, another explanation seems more convincing.

A total of 14 national and international guides and eight scientific publications from different countries were analysed. When considering the contexts of the analysed documents, it becomes apparent that they all address different building use classes and stakeholder groups. Against this backdrop, it seems plausible that the analysed documents had different target audiences dealing with different processes in the operational phase. This, in turn, led to different priorities regarding BIM uses supporting the provision of facility services. These differences might explain why some documents prioritised certain BIM uses because they were considered highly beneficial for the operation of the building use classes owned or operated by the target audience.

Regarding the generalisability of the defined BIM uses, some factors may limit the extent to which they apply to all industry sectors and countries. As the presented research focused on

CREM, the potential benefit of the identified BIM uses for CREM across all industry sectors remains to be investigated.

Based on the results of Cavka et al. (2017) and Munir et al. (2020), the industry sector of an organisation directly impacts its information requirements for processes in the operational phase. As BIM uses define and structure the information requirements for an underlying process, it can be assumed that the industry sector-dependence of information requirements extends to the BIM uses based on them. Further research might address these limitations by verifying whether the entirety of the identified BIM uses for CREM is indeed suited for implementation in all industry sectors. This might be achieved by conducting industry-specific studies assessing the benefit and implementation priority of the identified BIM uses for CREM. In addition, further research might also verify the applicability of the presented list of BIM uses for CREM in other countries or regions.

As the presented list is based on the German GEFMA 100-2, the contained FM processes as well as the derived BIM uses for CREM may differ fundamentally in other countries. This limitation might be addressed by investigating the applicability of the presented list of BIM uses for CREM in other countries. Alternatively, further research could also develop country-specific BIM uses for CREM based on national standards or guides to subsequently assess their benefit and their implementation priority. Ultimately, such research could help to define a list of internationally or Europe-wide acknowledged and standardised BIM uses for CREM in a yet-to-be-published catalogue.

The presented research made a first step in this direction by compiling a comprehensive list of BIM uses for CREM based on national and international documents and relevant research. Platforms like the “Use Case Management” by buildingSMART International (2023) promote the idea of a common understanding of BIM uses by publishing BIM use definitions, descriptions and delimitations. However, the published BIM uses are often only available in one language. In this context, the European integration and the ever-deepening single market might present an advantageous opportunity to incorporate national and European standards and guides as well as best-practice examples from the member states into a common understanding and cataloguing of BIM uses. This might contribute considerably to the digitalisation of the European AECO industry.

The second research trajectory assessed the implementation priority of the identified BIM uses for CREM. It showed that the overall benefit assessments of certain BIM uses varied considerably between respondents from different industries. Given the findings of Cavka et al. (2017) and Munir et al. (2020), this result was expectable, given the fact that CREM experts from several industry sectors participated in the underlying survey. Regarding the three BIM uses with the highest implementation priority — “Facilities and Equipment: Repair and Renewal”, “Defect Management”, and “Facility Identification System” — it can be observed that they are all maintenance-related. In the context of CREM, this confirms the findings of Wilkinson and Jupp (2016), concluding that the BIM-based delivery and handover of relevant information offers great potential for the enhanced execution of maintenance tasks. Furthermore, these results confirm the findings of Carbonari et al. (2018) who found that maintenance-related BIM uses had a high implementation priority based on their impact and the information requirements.

Nevertheless, a striking difference can be observed between the item “Asset records” defined by Carbonari et al. (2018) and the corresponding BIM use “FM Documentation: Management and Maintenance” defined in the presented research. The former is classified as a “high impact, high information” item resulting in a high implementation priority. The latter also received a high overall benefit assessment. However, this assessment was strongly industry sector-dependent. This indicates that the benefit assessments varied considerably between respondents and that the high overall benefit assessment is not generalisable.

Other BIM uses, like “Handover and Commissioning” and “Space and Room Management” scored a high overall benefit assessment but only for certain industry sectors. Based on these observations, further investigations might conduct industry sector-specific surveys to assess which of the identified BIM uses have the highest implementation priority in each industry sector based on the NACE Rev. 2 classification by the European Commission (2008).

The generalisability of the presented implementation priorities is also limited by two further factors. Firstly, the presented survey for data collection was conducted in German-speaking countries, i.e. Austria, Germany, and Switzerland. This limits the validity of the presented results to these countries. In a European context, it can be assumed that the results are likely to remain generalisable. Nevertheless, the results might turn out to be much less generalisable in a more international context. Organisations and CREM departments in countries with other climatic, economic, or infrastructural conditions are likely to have utterly different implementation priorities than the participating organisations in the presented survey. Therefore, further research might verify the implementation priority of the identified BIM uses for CREM in different countries or regions.

Secondly, the sample size of the presented survey might limit the meaningfulness of the associations between industry sectors and the overall benefit assessments of the BIM uses for CREM. The number of potential participants was by default severely constrained because of two eligibility criteria for partitioning in the survey, which were being a CREM expert and having prior BIM expertise. This limitation could not be overcome at the time of the presented research because of the limited BIM implementation in CREM. As many organisations have not yet started BIM implementation, their perspective was excluded from the presented results. This limitation may be addressed in future studies by conducting further surveys including more participants from more organisations.

The third research trajectory addressed the need to identify an accurate approach to AIR template definition for BIM uses. Thus, the presented research identified, applied, and compared approaches to the AIR template definition for BIM uses for CREM in the chemical industry. Furthermore, it provided the first iteration of AIR templates for four BIM uses for CREM with a high implementation priority. The BIM uses selected by the expert panel and their anticipated advantages concur with the findings of Tong et al. (2019), Chin et al. (2020), and Braun et al. (2022), highlighting the importance of the trouble-free operation of technical building services and the effective provision of facility services.

Regarding the selected information requirements, it can be observed that hygiene-, safety-, and maintenance-related information was considered particularly relevant. As the interviewed experts all came from the chemical industry, these observations concur with the findings of Tong et al. (2019) and Sheward (2021). Other selected information requirements, such as location, size, coverings or occupancy, are likely to apply to other industry sectors as well. Given the above-mentioned industry sector-dependence of BIM uses and information requirements, further research might aim to define generalisable "base AIR" applying to most, if not all, industry sectors. Such "base AIR" might then be completed with industry sector-specific "AIR extensions" accommodating the unique requirements and characteristics of each industry sector. A similar strategy might be applied to diversify the developed AIR template implementation framework. Limited modifications and additions might facilitate its implementation in different industry sectors.

Nonetheless, widespread BIM implementation might best be promoted not by adopting an approach based on individual industry sectors but by clustering and grouping industry sectors based on their shared characteristics and core business. Such an approach might aim to combine industry-specific AIR templates accommodating the distinctive features of various industrial sectors with generalised, basic AIR.

Based on the approved and rejected information requirements, the two identified approaches to AIR template definition were compared. The results show that the process-based approach is more suited to AIR template definition as it produces more accurate and, therefore, more generalisable AIR templates for CREM than the triangulation-based approach. However, none of the developed AIR templates achieved absolute accuracy among the interviewed expert panel, indicating that AIR templates always maintain a certain degree of inaccuracy and that customisations are necessary. However, this result was unexpected in the context of the triangulation-based AIR templates as the organisations that evaluated the AIR templates also provided the documents from which they were triangulated. This indicates that RDS and FIDS conventions may be overly project- or organisation-specific compared to simplified process diagrams. Still, this explanation is only partially supported by the reasons for the rejection of information requirements, as illustrated in Figure 14. This explanation remains tenable for the BIM use "Facility Identification System for Technical Building Services" as roughly 60 % of the defined information requirements were rejected because they were categorically unnecessary for the respective facility service. This result partially concurs with the findings of Tong et al. (2019) and Munir et al. (2020) who state that AIR templates will always maintain some degree of inaccuracy. In the case of the BIM use "Space and Room Management", however, the asset type or sub-type in question was almost as relevant for its accuracy as the categorical necessity of the information requirements.

This indicates that further research on BIM use-specific AIR for various asset types and sub-types might be required. Further research might focus on the specific AIR of asset (sub-)types that are relevant for a BIM use. Such research could define generalisable "base AIR" for an asset type, e.g. conveyor systems. Such base AIR could then serve as the foundation for asset sub-type-specific, adaptable AIR, such as passenger lifts or goods lifts. As suggested by Pasini et al. (2017), including such AIR in existing object libraries might further improve the applicability of AIR templates.

Several limitations are to be acknowledged regarding the defined AIR templates. Firstly, the fact that all RDS and FIDS conventions came from laboratory construction projects might impact the applicability of the defined AIR templates to other building use classes, in CREM as well as in the chemical industry. Further research might include a wider range of building use classes to verify the presented results or adjust the defined AIR templates.

Secondly, only four BIM uses for CREM were examined during the presented research. It is unknown whether the process-based approach also yields satisfactory results when applied to different BIM uses for CREM. Therefore, the accuracy of the process-based approach might be constrained when applied to different BIM uses for CREM. Further research applying the process-based approach to different BIM uses for CREM might address this limitation.

Thirdly, the process diagrams developed during the presented research are based on an input-oriented service-level approach. Different organisations may choose alternative strategies such as output-oriented service level strategies. The inclination of the participating organisations for an input-oriented service model led to this limitation. Further research might investigate whether different service level approaches affect the AIR for the provision of the underlying facility services.

The fourth research trajectory concerned the development of an AIR template implementation framework for owners and operators in CREM. Therefore, five recommendations for the implementation of AIR templates have been derived from the reasons for the rejection of information requirements.

Recommendation 1 states that the identification of necessary information requirements needs to be conducted in consideration of the ERP, CAFM, and CMMS software used by an organisation. In this context, Sacks et al. (2020) state that BIM offers great potential to close the gap between the planning and construction phases and the operational phase if applied correctly and in consideration of the involved software. However, such BIM-to-CREM information delivery requires the integration of BIM into existing ERP, CAFM, and CMMS structures, either as an additional platform or as data storage, as stated by Hewavitharana and Perera (2020) and (Lazar and McArthur, 2016).

Recommendation 2 states that static data should be prioritised when developing and implementing AIR templates, confirming the findings of Santos (2009). In this context, the findings of Chin et al. (2020) also indicate that static data might be the most efficient way to harness the potential of BIM for the provision of facility services in the context of CREM. According to Chen and Tserng (2017), Matarneh et al. (2019b), and Nojedehi et al. (2022), further research in this direction might not only define BIM-based information requirements but also address data exchange and interface challenges.

Recommendation 3 states that AIR templates require customisation before implementation. This result supports the findings of Munir et al. (2020), who concluded that "it may not be possible to develop a rigid list of requirements that apply to all asset owners" (Munir et al., 2020, p. 112). Therefore, a "one size fits all" approach is unlikely to be successful, and as-accurate-as-possible AIR templates may be the most efficient method to support owners and operators in CREM during BIM implementation. Still, further research may improve the accuracy of the presented results by including more organisations and industry sectors, as mentioned above.

Recommendation 4 concerns the definition of the asset type or sub-type, as mentioned above. Recommendation 5 states that stakeholders from all relevant CREM departments should be involved in the implementation process. This result concurs with the findings of Sheward (2021), indicating that inadequate and late stakeholder participation frequently results in poor decision-making. Furthermore, this recommendation addresses the findings of Blackburn et al. (2015) and Little et al. (2023), who identified the risks of late or inadequate stakeholder involvement. Further research might investigate processes or strategies to achieve effective stakeholder involvement, potentially based on lean principles or integrated project delivery methods.

The developed AIR template implementation framework for owners and operators in CREM extends the current state of research by focusing on the operational phase in this context. It adds to the results of Matarneh et al. (2019a) and the “information exchange framework” proposed by those authors by adding preceding steps for the definition of information requirement. However, the above-mentioned limitations regarding the generalisability of the defined BIM uses and AIR templates also limit the generalisability of the presented framework. Although the demographic validity and ecological validity of the research results were ensured, the results cannot be considered applicable to the entire chemical industry or even CREM in general. As mentioned above, this is due to the severely limited number of potential participants available to support this field of research. Accordingly, this limitation might also be addressed by including more organisations and stakeholders.

6 Conclusion and Outlook

The number of initiatives, programmes, and organisations promoting BIM implementation in the operational phase demonstrates its potential to support the digitalisation of the building sector as a whole. Still, BIM implementation in CREM has only been investigated to a limited extent, even though buildings accumulate the majority of their life cycle cost during the life cycle phase. One reason for this is the lack of templates or guides supporting owners and operators in CREM in the definition of information requirements.

The early consideration of information requirements for the provision of facility services in CREM requires extensive knowledge about BIM and an active involvement in the early project phases. This research gap holds even more true in the context of complex buildings relying on the frequent provision of extensive facility services. Owners and operators in CREM often struggle with the independent definition of information requirements for the provision of facility services as they lack the necessary knowledge, experience or resources. This often produces a lack of awareness regarding the possibilities of the BIM-based provision of facility services and the necessary process of information order. This problem is further exasperated by the fact that owners and operators in CREM often rely on guides and templates to initialise and execute tasks and processes.

There are currently no established catalogues of BIM uses for CREM, AIR templates or implementation frameworks regarding BIM-based facility services in CREM. Thus, related research suggests the identification of facility services that can be supported by BIM as well as the definition of respective BIM uses, as these are the first two challenges hampering BIM implementation in CREM. Furthermore, the definition of AIR templates and an implementation framework is suggested to support organisations in their endeavour to implement selected BIM uses independently.

Various approaches to AIR template definition already exist and their expedience has not been thoroughly investigated yet. Also, relevant research states that generalisations of information requirements across all industry sectors may only be partially accurate as the industry sector of an organisation affects its information requirements. This poses two further challenges to BIM implementation in CREM. The first is a need to identify the most accurate approach to the AIR template definition. Secondly, difficulties exist in defining generalisable information requirements and implementation steps across all industry sectors despite the industry sector-dependence of information requirements.

The presented research addressed these research gaps by identifying and defining BIM uses for CREM, assessing their implementation priority, defining AIR templates for CREM and identifying the most accurate approach to AIR template definition, and formalising their implementation in an AIR template implementation framework for owners and operators in CREM. Therefore, four research questions were defined and answered:

RQ 1: Which facility services can be supported through BIM uses in the context of CREM?

RQ 2: Which BIM uses for CREM have the highest implementation priority?
RQ 3: Which is the most accurate approach to the development of AIR templates for CREM?
RQ 4: How can the implementation of AIR templates be formalised for owners and operators in CREM?

RQ 1 and RQ 2 were investigated in Article 1 in the appendix and RQ 2 and RQ 3 were investigated in Article 2 in the appendix. The comparative analysis between 14 national and international guides on BIM implementation and the GEFMA 100-2 was initially conducted to identify BIM uses for the operational phase. The identified BIM uses were subsequently defined in the specific context of CREM. The results show that nearly all facility services defined in GEFMA 100-2 can be supported through BIM uses. A total of 35 BIM uses for CREM could be defined based on this comparative analysis. These findings affirm related research indicating that the operational phase offers numerous application areas for BIM-based facility provision.

Regarding the references to the identified BIM uses, certain discrepancies between the analysed sources could be observed. A plausible explanation for this is that the variety of the analysed documents regarding target audiences, countries, and building use classes inevitably finds expression in the reference to different BIM uses. A subsequent survey among CREM experts from Austria, Germany, and Switzerland identified BIM uses with a high implementation priority based on their overall benefit assessment and the industry sector-dependence of that assessment. It showed that maintenance-related BIM uses generally score higher implementation priorities across all industry sectors. Accordingly, BIM uses scoring a high implementation priority across all industry sectors are mainly maintenance-related. These are “Facilities and Equipment: Repair and Renewal”, “Defect Management”, and “Facility Identification System”. In contrast, the expected benefit from the implementation of certain BIM uses varied considerably between respondents from different industries. This confirms related research indicating that the individual information requirements and, by consequence, prioritised BIM uses are linked to the industry sector of an organisation. In contrast, BIM uses like “Handover and Commissioning” and “Space and Room Management” scored high overall benefit assessments but only within certain industry sectors.

Approaches to the generalisation of AIR templates were subsequently identified, applied, and compared to develop documents supporting the implementation of BIM uses for CREM. This showed that the most relevant research on the AIR template definition applied either a triangulation-based or a process-based approach.

To accommodate the findings regarding the industry sector-dependence of information requirements, the subsequent application and comparison of both approaches was conducted in the context of the chemical industry. An expert panel from the chemical industry selected the following BIM uses for AIR template development and comparison: “Space and Room Management”; “Maintenance Cleaning Management”; “Facility Identification System for Technical Building Services”; and “Expert Examination, Inspection, and Maintenance of Conveyor Systems”. This selection of BIM uses confirmed the previously assessed implementation priority of maintenance-related BIM uses. Furthermore, it concurred with relevant research identifying the importance of the trouble-free operation of technical building services and facility service delivery in the chemical industry. This shows that process-based AIR templates yield more accurate and, therefore, more generalisable AIR templates for CREM in the chemical industry. Furthermore, hygiene-, safety-, and maintenance-related information is of particular, potentially distinctive, relevance for this industry sector. Several other selected information requirements, however, are likely to be applicable and generalisable to other industry sectors as well.

Five recommendations were derived from the reasons for the rejection of information requirements to formalise the implementation of AIR templates. Recommendation 1 suggests the initial examination of information management processes to accommodate the prevalence of current ERP, CAFM, and CMMS software architectures in modern CREM. Recommendation 2 suggests the prioritisation of static data in AIR templates. Recommendation 3 suggests that the individual customisation of as-accurate-as-possible AIR templates may be the most effective and suitable approach for their implementation. Recommendation 4 suggests the definition of sector-specific catalogues of information requirements for certain asset types serving as the root for information requirement extensions for asset sub-types. Recommendation 5 suggests early and comprehensive involvement of all CREM stakeholders in the AIR definition, customisation, and implementation process. These recommendations were translated into an AIR template implementation framework for owners and operators in CREM. It formalises the derived recommendations in three main stages: customization, selection, and mapping of information requirements. It is designed in a 12-step flow chart with three lanes representing the three relevant stakeholders in AIR definition and implementation.

The presented research establishes the foundation for further research and expands the current scientific knowledge in this field by providing a total of four contributions. Firstly, it provides a list of BIM uses supporting the provision of facility services in CREM. Secondly, BIM uses with a high implementation priority across all industry sectors have been identified. Thirdly, an accurate approach to the AIR template definition has been identified and the first iteration of AIR templates has been provided for four BIM uses for CREM in the chemical industry. Fourthly, it provides an AIR template implementation framework for owners and operators CREM in the chemical industry and other industry sectors. Several limitations impair the generalisability of the presented results. Based on relevant research and these limitations, the following further research directions are suggested:

- Industry sector-specific studies on the benefit of BIM uses for different industry sectors to verify the applicability and assess the implementation priority of the identified BIM uses in further industry sectors
- Country- or region-specific studies based on the presented list of BIM uses to verify the applicability and implementation priority of the identified BIM uses in further countries or regions and potentially promote the identification of country-specific BIM uses
- The definition of a list of internationally or Europe-wide acknowledged and standardised BIM uses for CREM in a yet-to-be-published standard promoting a common understanding and cataloguing of BIM uses

- The definition of common "base AIR” for all industry sectors or industry sector clusters constituting a root for additional, characteristic, and industry-specific "AIR extensions". A similar approach might be adopted for the developed AIR template implementation framework
- The development of “base AIR” for relevant asset types for certain BIM uses constituting a root for additional, asset sub-type-specific information requirements
- The inclusion of a wider range of building use classes in future studies to verify or adjust the presented results
- The investigation of whether different service level approaches affect the information requirements needed for the provision of the underlying facility services
- The involvement of more organisations and stakeholders in future studies to allow the generalisation of the presented results and to enhance their demographic and ecological validity

As BIM implementation in the AECO industry progresses, CREM will need to find ways to achieve BIM implementation while accommodating its unique characteristics and challenges. Still, it is unclear whether excessively detailed or precise BIM use categorisations and definitions, AIR templates or implementation frameworks would be appropriate for the diverse environment of modern CREM. The current study encourages owners and operators in CREM to select BIM uses based on a pre-defined catalogue and to develop or apply AIR templates as a starting point for individual customization. The definition of process-based AIR templates offers a tool required to take on pilot projects, promoting BIM implementation in CREM in the chemical industry and other sectors.

Article 1

buildings

MDPI

Article

BIM for CREM: Exploring the Benefit of Building Information Modelling for Facility Management in Corporate Real Estate Management

Maximilian Benn * and Christian Stoy

Institute for Construction Economics, University of Stuttgart, Keplerstraße 11, 70174 Stuttgart, Germany; info@bauoek.uni-stuttgart.de
* Correspondence: maximilian.benn@bauoek.uni-stuttgart.de

Abstract: The implementation of BIM in FM has been of steadily growing interest for academic research. Yet the benefits of BIM for the FM in CREM have, to the present day, been explored to a limited extent. As research on BIM for FM in CREM remains narrowly investigated, this study follows an exploratory approach to formulate implications for further research directions. Therefore, a four-stage procedure was adopted: (1) identification and definition of BIM uses for FM in CREM; (2) validation of the BIM uses for FM in CREM and the expert survey questionnaire; (3) assessment of each BIM use's benefit by experts; and (4) analysis of the correlations between BIM uses' benefit assessments and the respondents' industries, the resulting associations, and the prioritisation for the development of BIM uses for FM in CREM. Based on that methodology, it was shown that the BIM use for FM in CREM with the highest priority for development is 46 Facilities and Equipment: Repair and Renewal. The BIM use with the lowest priority is 21 Visualisation. As a result, four implications on the development of BIM uses for FM in CREM were formulated regarding case studies, information requirements, and technical requirements, as well as process and personnel requirements.

Keywords: building information modelling (BIM); corporate real estate management (CREM); facility management (FM); BIM use; benefit; industry; expert survey; exploratory approach

check for updates

Citation: Benn, M.; Stoy, C. BIM for CREM: Exploring the Benefit of Building Information Modelling for Facility Management in Corporate Real Estate Management. *Buildings* **2022**, *12*, 400. https://doi.org/10.3390/buildings12040400

Academic Editor: Junbok Lee

Received: 9 February 2022
Accepted: 23 March 2022
Published: 25 March 2022

1. Introduction

Digitisation in the construction sector remains delayed compared to most other industries, even though it has been accelerated considerably by the advent of technologies such as the internet of things (IoT), 3D scanning, distributed ledger technologies (DLT), and—arguably most prominent—building information modelling (BIM) [1–4]. Accordingly, actors such as the EU BIM Task Group identified the implementation of BIM as "the construction sector's moment of digitisation" for all building life cycle phases [5] (p. 8). Among the beneficial implications of BIM implementation, direct or indirect financial benefits are among the most frequently mentioned. Estimations regarding the cost-saving potential through BIM are assessed between 8% and 23%, depending on the buildings' life cycle phase [6].

Concerning a building's life cycle cost, it is widely acknowledged that the cost accumulating during the operational phase greatly exceeds the cost of the design and construction phase combined. Nevertheless, estimations vary regarding the operational phase's precise percentage of the overall life cycle cost. This may extend from 60% [7] to 80% [8] and even up to 85% [9] of a building's total life cycle cost accumulating during the operational phase. Given the impact of a building's operational phase on its life cycle cost, potential cost savings by implementing BIM in that life cycle phase are expected to be considerable. Therefore the implementation of BIM in facility management (FM) has been of steadily growing interest for academic research [10].

However, the benefits of BIM for the FM in corporate real estate management (CREM)—i.e., the management of real estate that is related directly to an organisation's core business [11,12]—have, to the present day, been explored to a rather limited extent [13]. Corporate real estate can be defined as "all forms of properties that corporates need for the execution of their core business, including administrative buildings, social buildings, training centres, research and application technology buildings, agricultural buildings such as greenhouses, etc." [11] (p. 6).

In a prototypical case study, Gerbert et al. [6] evaluated the impact of BIM implementation on the life cycle cost of different building types. Results showed that of all buildings compared, the highest cost-saving potential of 14% to 23% was identified within the group of commercial and institutional buildings. These findings support the assumption that BIM offers great benefit for FM in CREM, as real estate operation often presents one of the biggest cost blocks for companies [11]. Nonetheless, BIM implementation in this specific context progresses unevenly. Of the many obstacles encountered, one that has been identified repeatedly lies within the identification of FM processes and corresponding BIM uses for implementation [14–16]. A second one lies within the subsequent implementation due to a lack of guides and standardisation documents for specific BIM uses, posing a challenge to many FM professionals [10,14]. Within this context, related research furthermore suggests that different industries might have different implementation priorities based on benefit assessments of specific BIM uses for FM in CREM [16,17].

In order to accelerate the implementation of BIM for FM in CREM, high-priority BIM uses for FM in CREM providing a high benefit for all industries must be identified. This allows the identification of further research directions regarding the development of guides and templates for high-priority BIM uses for FM in CREM.

Consequently, this study focuses on the benefit assessments of BIM uses for FM in CREM and their association with industries. In order to outline this study's objectives, four questions have been formulated:

1. RQ 1: Which BIM uses supporting FM processes in CREM can be identified?
2. RQ 2: How do experts assess the benefit of BIM uses for FM in CREM?
3. RQ 3: How strong are the associations between each BIM use's benefit assessment and the respondents' industries?
4. RQ 4: What prioritisation for the development of BIM uses for FM in CREM can be derived from the BIM uses' benefit assessments and their association with industries?

Regarding RQ 2, related studies by Becerik-Gerber et al. [18] and McArthur and Sun [19] investigated the benefit of selected BIM uses. Since both studies focus on the complete life cycle within a heavily public real-estate-related context, no prior hypothesis could be deduced from them. Regarding RQ 3, no prior hypothesis has been proposed as related research indicating such associations is still too limited to allow substantiated assumptions—notably by Munir et al. [17] and Cavka et al. [16]. Given the limited amount of prior related research, this study consequently follows an exploratory approach to distinguish implications and further research directions [20,21].

2. Methodology

To investigate BIM for FM in CREM and deduce implications as well as further research directions, this study follows an exploratory approach. Exploratory approaches are applied to fields with little or no prior body of knowledge or theories [20,21]. Thus, a four-stage mixed-methods procedure was adopted, as shown in Figure 1: (1) identification and definition of BIM uses for FM in CREM; (2) validation of the identified BIM uses for FM in CREM and the expert survey questionnaire; (3) assessment of each BIM use's benefit by experts; and (4) analysis of the correlations between BIM uses' benefit assessments and the respondent's industries, the resulting associations, and the conclusive prioritisation for the development of BIM uses for FM in CREM. Each stage conducted during this study is further elaborated in the following paragraphs of this section.

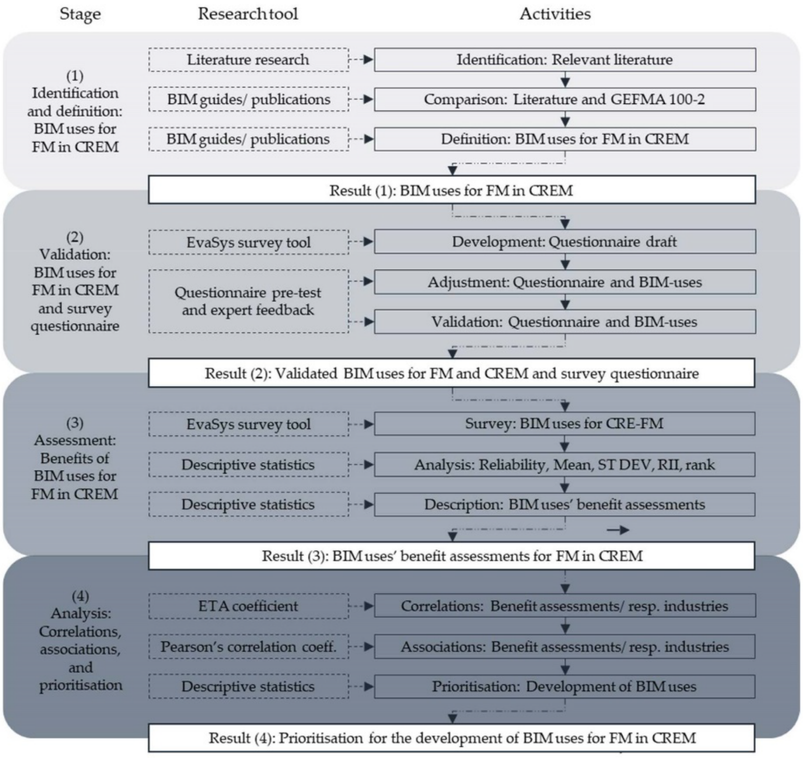


Figure 1. Research methodology.

Stage (1) aims at identifying literature for creating a baseline catalogue of BIM uses supporting FM processes in CREM. To do so, three steps were conducted during this stage. Initially, the determination of sources was accomplished through systematic literature research and analysis of reports on international BIM maturity to identify leading nations in BIM implementation. The literature research aimed at identifying BIM guides provided and published by state organisations or NGOs that outline terminology and BIM uses that are already established, thus known by experts. The keywords included: BIM; Building Information Modelling; BIM guide; BIM guideline; BIM standard; BIM use; BIM use case. The databases for literature research included: Web of Science, Google Scholar, and Engineering Village. In terms of internationally leading countries with high BIM maturity levels, the UK, Singapore, China, Hong Kong, Finland, Norway, and the United States were identified [22]. On a European level, the Netherlands, Spain, France, and Germany are also rapidly accelerating their BIM implementation efforts [23]. A total of 14 international BIM guides were identified and used as a source for BIM uses in FM. Subsequently, the BIM guides identified were systematically analysed and matched with the list of FM processes provided by the German Facility Management Association e.V. [24] in their GEFMA 100-2 guideline. This guideline contains a comprehensive list of categorised FM main processes and corresponding FM processes developed by an expert committee, making it a reliable reference structure. Comparative analysis of the 14 international BIM guides with GEFMA 100-2 resulted in the first list of 34 BIM uses for FM as a base for further elaboration. To define the BIM uses specifically for FM in CREM, a second literature analysis addressing this specific context was conducted [11,25].

The second literature review aimed at the identification of scientific publications on BIM in a CREM context. The keywords included: BIM; Building Information Modelling; BIM use; BIM use case; Facility Management (FM); Operations; Maintenance; O&M; Corporate Real Estate (CRE). The databases for literature research included: Web of Science, Google Scholar, and Engineering Village. A comparative analysis of the guides used in the first stage as well as the scientific publications identified in the second stage allowed the development of specific definitions of BIM uses supporting FM processes in CREM. The result of the comparative analysis is shown in Table A1.

Stage (2) comprises the expert validation of the BIM uses for FM in CREM as well as the validation of the survey questionnaire. Preparatory expert validation was conducted during a pretest involving FM experts in CREM with BIM experience. Therefore, the list of BIM uses for FM in CREM from stage (1) and a draft of the survey questionnaire were prepared for validation. The pretest then allowed the validation of both the list of BIM uses and the survey questionnaire. Participants were explicitly informed of the pretest status, encouraging a critical view of the questionnaire to improve feedback [26]. Based on the pretest feedback, the questionnaire's processing time could be asserted and one further BIM use was added: 63 Cleaning Management: Outdoor Facilities Cleaning. As a result, stage (2) provided a validated expert survey questionnaire comprising a comprehensive list of BIM uses for FM in CREM, answering this study's RQ 1.

Stage (3) consists of an initial online survey targeting experts for FM in CREM with prior BIM experience. The pool of possible participants was assumed to be rather limited due to the prerequisite of having experience in the fields of CREM and BIM. Hence, a cross-section online survey was chosen for data collection to reach a larger number of potential participants [27]. Questionnaire distribution by the Austrian IFMA Austria, the German RealFM e.V., and the Swiss SVIT FM Schweiz ensured that purposive sampling was restricted to the predefined target group of experts for FM in CREM with BIM experience [27]. Starting the questionnaire, participants were asked to (1) confirm that they have understood the prerequisites for participating in the study regarding FM and BIM experience, (2) state their position in the organisation they work for, and (3) state their own or their customers' industry, following the SNA/ISIC intermediate aggregation A 38 of economic activities by the European Commission [28]. Question (1) actively reminds the respondents of the requirements to ensure purposive sampling. Question (2) considers the participants' point-of-view from an operational, tactic, or strategical level. Question (3) ensures that only data from experts with experience in CREM are included in the analysis. Eventually, all participants were asked to assess each BIM use's benefit on a 5-point scale from (1—very low benefit) to (5—very high benefit). Concerning terminology, the term "benefit" was selected due to its utilisation for the evaluation of positive effects of BIM in FM in several related publications [3,29], notably [19]. The results' internal consistency was measured by determining Cronbach's alpha [30]. The subsequent analysis of valid responses was performed conducting data description and analysis techniques.

Stage (4) aimed at answering RQ 3 and 4 by further analysing the results from stage (3). The measurement of correlations was conducted by calculating each BIM use's ETA coefficient depending on the respondents' industries. As a result of the calculated ETA coefficients, the association between each BIM use's benefit assessment and the respondents' industries could be determined by applying Pearson's correlation coefficient [31]. Conclusively, each BIM use's benefit assessment and their association with the respondents' industries were used to derive a prioritisation for the development of BIM uses for FM in CREM to answer RQ 4.

3. Scientific Background

3.1. CREM

Concerning the precise definition and delimitation of CREM, the term corporate real estate (CRE) requires a prior definition. Heywood and Kenley [12] describe two possible definitions: either including all real estate owned by a company—core-business-related or not core-business-related—or only including real estate being related directly to the core business of a company, provided that the core business is not real estate. As Heywood and Kenley [12] favour the latter definition, Glatte [11] equally defines CRE as core-business-related, "including all forms of properties that corporates need for the execution of their core business, including administrative buildings, social buildings, training centres, research and application technology buildings, agricultural buildings such as greenhouses, etc." [11] (p. 6). Predominant building types in CRE are buildings for offices, storage, production, and/or retail, depending on the company's industry [8,32]. In this context of direct relation to a company's core business, aligning CREM objectives with a company's strategic goals can contribute greatly to its success. This can be achieved in multiple ways, including "property management, handling facilities, reducing operating cost, and many other contributions [. . .]" [33] (p. 61). According to Glatte [11], CREM, therefore, includes the aspects of asset management, property management, and building management of FM, whereas infrastructural facility services of FM stand apart, as shown in Figure 2.

Figure 2. Disciplines of corporate real estate management and infrasturctural facility services.

3.2. CREM and FM

The exact relationship between CREM and FM gives rise to discussions within the community of FM and CREM experts [34,35]. van der Voordt [34] affirms that FM and CREM do share similarities regarding conferences and organisations and that both align to corporate strategies. Concerning disparities, van der Voordt [34] distinguishes two main differences between FM and CREM: (1) FM focuses on non-core business services and their management whereas CREM focuses on the integration of management disciplines and cost control; and (2) CREM focuses on real estate as an asset used for its purpose, whereas FM is service-oriented and therefore focuses on demands related to space, infrastructure, people, and organisations.

Nonetheless, van der Voordt [34] observes a clear convergence between CREM and FM and an ever-increasing integration and alignment of both. This raises the question of future terminology, as shown in Figure 3.

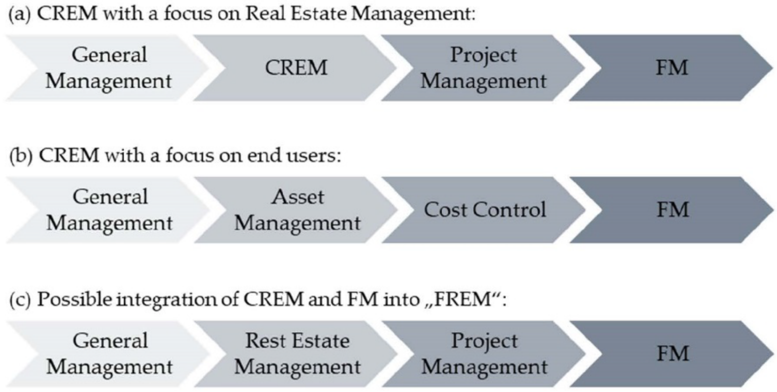


Figure 3. (**a**) CREM with a focus on real estate management; (**b**) CREM with a focus on end users; (**c**) Possible integration of FM and CREM into FREM (according to van der Voordt [34]).

As the question of the exact relationship of CREM and FM remains disputed and the question of the terminology itself provides ample material for discussion, this publication cannot give terminology describing the relationship of CREM and FM conclusively. Instead, the term "FM in CREM" is applied to describe all aspects of asset, property, and building management and those of infrastructural facility services, constituting FM in CREM.

3.3. BIM for FM

ISO 41011:2017 defines FM as an "organizational function which integrates people, place and process within the built environment to improve the quality of life of people and the productivity of the core business" [36] (p. 1).

Previous studies have shown that FM can benefit in several ways from the implementation of BIM: gains in efficiency due to automatic generation of geometric information for FM [37], advanced decision-making and data management [38], optimised communication and coordination of FM processes [15], enhanced collaboration [39], improved building performance [40], and enhanced levels of competitiveness [41] are some examples. Even though research on BIM implementation in FM has intensified recently, its application in the FM industry remains rather limited compared to design and construction [10,25,42,43]. In this context, the identification of FM processes and corresponding BIM uses for implementation constitutes a major obstacle hampering BIM implementation in FM [14–16].

BIM uses can be defined as "a method or strategy of applying Building Information Modelling during a facility's lifecycle to achieve one or more specific objectives" [44] (p. 5). The achievement of these specific objectives through BIM uses is a core concept of BIM implementation. In the case of FM, these specific objectives often describe generating a benefit for FM processes through information stored in or extracted from a BIM [16,45].

Due to the BIM workflow concentrating efforts in earlier planning phases, the identification of BIM uses shifts to earlier project phases accordingly, as shown in Figure 4. Therefore, BIM uses need to be identified in early project phases, beginning with the end in mind [46]. Since FM has highly accurate and specific information requirements, early identification of beneficial BIM uses is essential for information collection and delivery to effectively implement identified BIM uses [37,45,47–49].

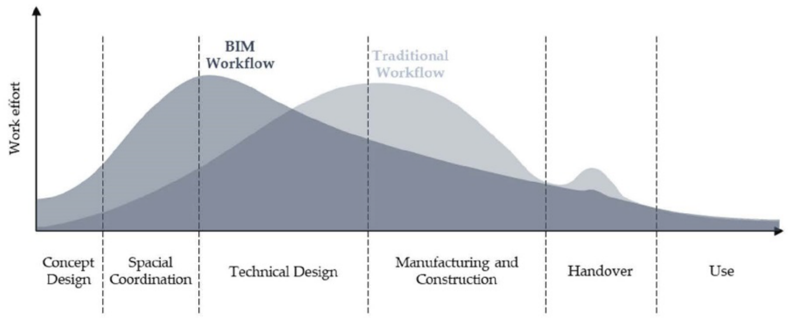


Figure 4. Effort distribution on the life cycle phases in the traditional workflow compared to the BIM workflow [50].

As many FM professionals still struggle with adopting BIM for FM in general, the initial identification of BIM uses based on supported FM processes poses an additional challenge to many [15,49,51]. Alshorafa and Ergen [14] point out that "there is no guidance to determine what information should be included in a BIM model for different BIM uses" [14] (p. 564). Correspondingly, Miettinen et al. [52] identified insecurity about BIM benefits and applications in FM as one of the biggest concerns for professionals. To tackle these barriers to BIM implementation in FM, Edirisinghe et al. [10] conclude that further research is required concerning the development of specific BIM applications for FM. Recently, the German standardisation organisation DIN correspondingly proposed the analysis of BIM uses to lay the ground for standardisation and template development [53].

3.4. BIM for FM in CREM

CREM portfolios are often large and diverse, comprising a variety of sometimes highly complex buildings [25]. Hence, FM in CREM represents a particularly intriguing field of BIM application with a variety of potential applications. It is essential to determine which information for which FM processes is relevant for CREM to efficiently operate buildings, as data and information management itself can be a considerable cost factor [13]. The definition of BIM uses should therefore be conducted carefully and in direct correspondence to objectives and FM processes.

Research also suggests that organisation types are a factor influencing the identification of beneficial BIM uses for FM in CREM. In their 2020 study, Munir et al. [17] analysed and compared the type and nature of information needs of different organisation types. The authors concluded that there is a strong relationship between an organisation's industry and the FM processes it wants to support with BIM, based on its objectives and asset management strategy. Cavka et al. [16] made a similar observation when investigating the BIM information requirements of large owner organisations. They found that requirements vary considerably between organisations from different industries, as BIM-supported FM processes vary. Based on Munir et al. [17] and Cavka et al. [16], it can therefore be assumed that different industries assess the benefit of specific BIM uses for FM in CREM differently.

4. Research Background

4.1. Related Studies: BIM in FM

In recent years, research on BIM uses for FM has intensified considerably [54]. Several studies concerning their identification and definition in different contexts have been published. However, the focus often lies on the information requirements themselves. Without a link to specific FM processes within a specific context, BIM use identification may only be conducted during project execution, jeopardising the principles of "beginning with the end in mind" [46]. Table 1 shows related studies that have been analysed for the identification of BIM uses for FM.

Table 1. Related studies investigating BIM uses for FM.

Authors	Year	Approach
Becerik-Gerber et al. [18]	2012	Potential FM application areas that BIM can be used for, mainly within the context of PRE
McArthur and Sun [19]	2015	Analysis and prioritisation of BIM uses in public-private partnerships in different industries
Mayo and Issa [55]	2016	Examination of BIM use information requirements based on categories within the context of PRE
Cavka et al. [16]	2017	Definition of owner information requirements based on O&M functions within the context of PRE
Miettinen et al. [52]	2018	Analysis of the current state of implementation of BIM for FM within the context of PRE
Alshorafa and Ergen [14]	2020	Definition of specific IR and their LOD, depending on BIM uses for FM identified during an expert survey

4.2. Related Studies: BIM Uses for CREM

Even though research on BIM in FM has been growing steadily, studies focusing on its implementation in the context of CREM are rare. Within the studies identified, two approaches could be determined. The first one started with the information that can be stored in a BIM and investigated which information might be potentially beneficial to CREM professionals or processes [56]. The second approach identified CREM processes initially and, based on that, looked for potential benefits through BIM and useful information [25]. Table 2 shows related studies analysed for the identification of BIM uses for CREM.

Table 2. Related studies investigating BIM uses for CREM.

Authors	Year	Approach
Lazar and McArthur [56]	2016	Case study demonstration of BIM data visualisation benefits within the context of CRE
Carbonari et al. [25]	2018	Analysis of possible BIM application areas for operations within the context of CRE

5. BIM Uses for FM in CREM

As described in Section 2, the list of FM processes provided by the German Facility Management Association e.V. [24] in the GEFMA 100-2 guideline constitutes the baseline for identifying BIM uses for FM in CREM. It defines nine FM main processes and their corresponding FM processes for the operational phase. Eight out of nine FM main processes and their FM processes are included in this study. FM main process number nine was excluded as it covers refurbishment projects during the operational phase, making it construction-related. For clarity, BIM uses were clustered based on the GEFMA 100-2 FM main processes, as shown in Table 3.

Based on Table 3, a total of 35 distinct BIM uses for FM in CREM could be identified, answering RQ 1.

Table 3. Identified BIM uses for FM in CREM.

FM Main Process	No.	BIM Use
1 Commissioning	11	Handover and Commissioning
	12	As-Built Modelling and Documentation
2 Manage Operations	21	Visualisation
	22	Disaster Planning and Emergency Preparedness
	23	Wayfinding and Tracking
	24	Generate: 2D Plans and 3D Details
	25	FM Documentation: Management and Maintenance
	26	Ticket Management
	27	FM Quality Management
	28	FM Sustainability and Environmental Protection
3 Provide Workplaces	31	Space and Room Management
	32	Relocation Management
	33	Equipment and Furnishing
4 Operations	41	BIM 2 Field
	42	Structural Health Monitoring
	43	Facility Identification System
	44	Facilities and Equipment: Periodic Inspections
	45	Facilities and Equipment: Inspection and Maintenance
	46	Facilities and Equipment: Repair and Renewal
5 Supply and Disposal	51	Real-time Acquisition and Display of Sensor Data
	52	Energy Management
	53	Waste Management
6 Cleaning and Maintaining	61	Cleaning Management: Maintenance Cleaning
	62	Cleaning management: Glass and Facade Cleaning
	63	Cleaning Management: Outdoor Facilities Cleaning
7 Asset Management	71	Security Management
	72	Locking Management
	73	Rent Management
	74	Generate: Inventory, Component, and Equipment Lists
	75	FM Accounting and FM Controlling
	76	Perform Contract and Insurance Management
	77	Defect Management
8 Provide Support	81	Room Booking and Occupancy Systems
	82	Event Planning
	83	Perform Procurement

6. Online Survey

6.1. Questionnaire

For the assessment of each BIM use's benefit and the investigation of potential correlations between benefit assessments and respondents' industries, an online expert survey was designed and distributed via German-speaking FM associations as described in Section 2. The questionnaire itself targeted the study's RQ 2–4. Experts were asked to state their industry based on the SNA/ISIC intermediate aggregation A 38 of economic activities by the European Commission [28] as well as their position before assessing the benefit of each BIM use from (1—very low benefit) to (5—very high benefit).

6.2. Survey Distribution

The distribution of the finalised questionnaire was supported by three leading FM associations, as described in Section 2. To maximise the number of potential participants, each association distributed invitations to the survey by their respective newsletters. As the participants' experience within the fields of CREM and BIM was a prerequisite for receiving valid and meaningful results, the letter also explicitly stated that the survey addressed experts with experience in both fields.

6.3. Data Collection

After the survey distribution, the data collection lasted from September 2021 until January 2022. The rather extended data collection phase was due to different distribution dates of the online survey by each supporting association. During the data collection, a total of 38 responses from CREM experts were collected. One response had to be excluded due to implausible data, resulting in 37 responses included in the data description and analysis.

7. Data Description and Analysis

Regarding the respondents' demographic distribution, it was shown that the largest groups of respondents are those from the construction and human health services industries, followed by the chemicals and chemical products industry, as shown in Figure 5.

Figure 5. Distribution of respondents' industries ($n = 37$).

Regarding the respondents' positions within their respective companies, 19% of the respondents have a position on the executive level, 57% on the management level, and 24% on the operational level, as shown in Figure 6. It can therefore be assumed that assessments collected during this survey mainly display the management perspective, i.e., the tactical perspective, on BIM in FM for CREM.

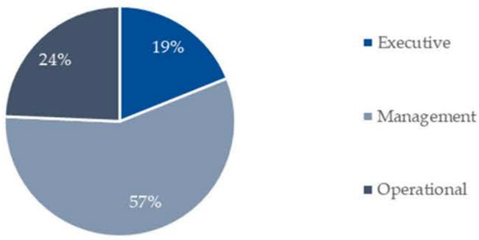


Figure 6. Distribution of respondents' positions ($n = 37$).

The calculation of each BIM use's benefit assessment was conducted by determining their arithmetic mean (AM). Thirty-five items were included in the benefit assessment and the formula was applied accordingly. The arithmetic mean was calculated using the formula:

$$\tilde{x} = \frac{1}{n} \times \left(\sum_{i=1}^{n} x_i \right)$$

With $\tilde{x}$ = weight given to response, n = number of items in the sample, and $\sum_{i=1}^{n} x_i$ = the sum of the sampled values, the arithmetic mean of each BIM use's benefit assessment was calculated based on the respondents' assessments. The arithmetic mean of each BIM use's benefit assessment is shown in Figure 7, answering RQ 2.

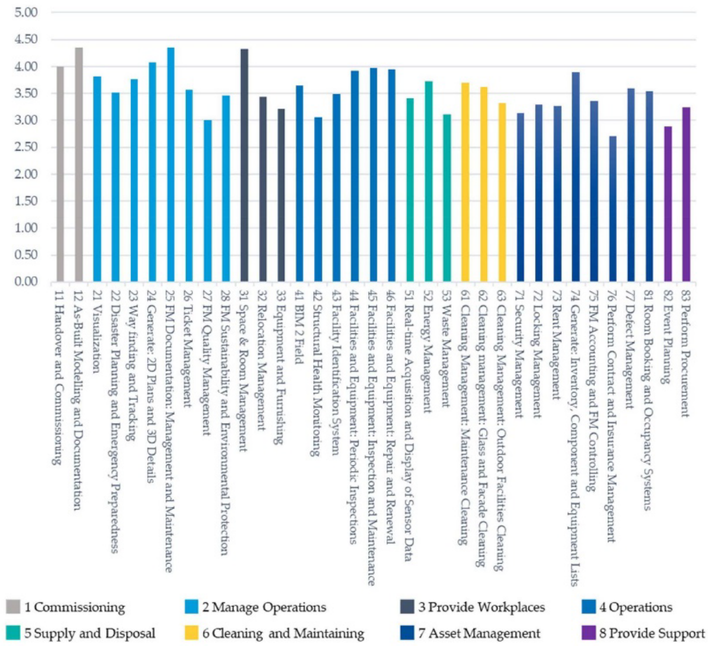


Figure 7. The arithmetic mean of BIM uses' benefit assessments from (1—Very Low Benefit) to (5—Very High Benefit) (n = 38).

The internal consistency measurement of the constructs examined in the survey was performed by analysing Cronbach's alpha for each FM main process. The reliability for each FM main process was therefore calculated based on the BIM uses constituting them, meaning a total of 35 variables. When analysing Cronbach's alpha, values of $\alpha \geq 0.6$ per construct are acceptable for exploratory studies while $\alpha \geq 0.7$ is considered desirable, with the limitation that too high values of $\alpha \geq 0.9$ may indicate redundancies within the construct [20,57]. As Table A2 shows, the values for each main process range from $\alpha = 0.683$ to 0.932, indicating adequate interrelatedness of the BIM uses within each FM main process.

The determination of the association between each BIM use's benefit assessment and the respondents' industries was conducted by calculating their respective ETA coefficients. The ETA coefficient is a method to determine the correlation between an independent categorical variable (e.g., blood type, profession, hair colour) and a dependent scale variable (e.g., Likert, temperature, weight) [31].

For this study, the respondents' industries were captured as a categorical variable and each BIM use's benefit assessment as a scale variable. The calculation of the ETA coefficients was conducted using the formula:

$$\eta = \frac{\frac{1}{n-1} \times \sum_j^k \times n_j (\overline{y}_j - \overline{y})^2}{s_y^2}$$

With n = number of items, $\overline{y}$ = mean value of the variable, and s_y = variance of $\overline{y}$. Interpretation of the Pearson's correlation coefficient shown in Table 4 indicated the association between each BIM use's benefit assessment and the respondents' industries.

Table 4. Pearson's correlation coefficient for the interpretation of the ETA coefficient.

Pearson's Correlation Coefficient	Interpretation
0.00	No association between the two variables
0.01–0.19	No or negligible association between the variables
0.2–0.39	A weak association between the variables
0.4–0.69	Medium association between the variables
0.70–1.0	Strong association between the variables

Only questionnaires from industries with at least two responses could be included in the correlation analysis. Thus, $n = 33$ for the ETA coefficient calculation and subsequent association determination.

By interpreting Pearson's correlation coefficient presented in Table 4, the results shown in Figure 8 can be analysed to determine the association between each BIM use's benefit assessment and the respondents' industries. As described in Table 4, an ETA coefficient of $\geq$0.7 indicates a strong association, an ETA coefficient of 0.4–0.69 indicates a medium association, and an ETA coefficient of 0.2–0.39 indicates a weak association between the variables. Thus, a low ETA coefficient suggesting that a BIM use's benefit assessment only has a weak association with specific industries is desirable in this context.

The interpretation of the results shown in Figure 8 thus answer RQ 3. Particularly strong associations can be identified for the BIM uses 11 Handover and Commissioning; 21 Visualisation; 25 FM Documentation: Management and Maintenance; and 31 Space and Room Management.

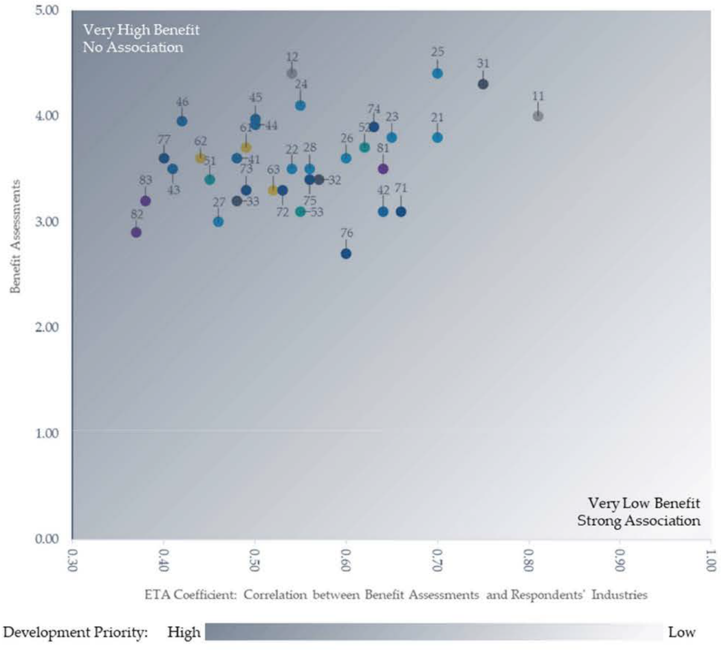


Figure 8. BIM uses' benefit assessments and their respective correlation to the respondents' industries as ETA coefficient ($n = 33$).

The BIM uses' benefit assessments in connection with the determination of their respective associations with the respondents' industries also allow one to derive a prioritisation for the development of BIM uses for FM in CREM. Given the measured differences regarding the BIM uses' benefit assessments as well as the strength of their respective association, it can be assumed that some BIM uses are of high or very high benefit for FM in CREM in general, regardless of the specific industry. This assumption is based on the observation that those BIM uses' benefit assessments show only medium to weak associations with the respondents' industries. Consequently, it can also be assumed that some BIM uses are of high to very high benefit for FM in CREM but that their benefit assessments are highly associated with the respondents' industries, questioning their benefit for CREM in general.

Following these assumptions, prioritisation for the development of those BIM uses can be derived, answering this study's RQ 4. Due to their assumed benefit for FM in CREM regardless of the specific industry, BIM uses with a weak to medium association with the respondents' industries are by default considered to be of higher priority than BIM uses with strong associations with the respondents' industries, as shown in Figure 9.

The prioritisation for the development of BIM uses for FM in CREM has been conducted based on their respective benefit assessments and ETA coefficients. Since the benefit assessments and the ETA coefficients are not directly comparable, the weighted product model was chosen for determining each BIM use's score. The weighted product model can be applied in multi-criteria analysis to determine the value of non-comparable units, as it is dimensionless. This means it eliminates units and can be applied to relative values instead of actual ones, making it a more suitable choice than the weighted sum model [58,59]. Each BIM use's weighted product has been calculated using the formula:

$$A_j^{WPM} = \prod_{j=1}^{n} x_{ij}^{w_i}$$

With A_j^{WPM} = weighted product score, n = number of criteria, x_{ij} = the actual value of the ith alternative in terms of the jth criterion, and w = the weight of importance of the jth criterion. Weightings have been determined neither for the BIM uses' benefit assessments nor for the ETA coefficients. Regarding each BIM use's ETA coefficient, $(1 - x_{ij})$ = the actual value of the ith alternative in terms of the jth criterion. Thus, by multiplying each BIM use's benefit assessment with its respective ETA coefficient, each BIM use's multiplicative score could be determined [59]. Based on the weighted product model, BIM uses with a high benefit assessment and weak to medium associations are considered to be of high priority for the development of BIM uses for FM in CREM in general. Accordingly, BIM uses with a low benefit assessment and strong associations are considered to be of low priority for the development of BIM uses for FM in CREM in general.

Figure 9. Prioritisation for the development of BIM uses for FM in CREM [60].

8. Discussion

Utilising the potential of BIM for FM in CREM remains a challenge and numerous obstacles remain to be tackled and overcome. Of those obstacles, one lies within the initial identification and definition of BIM uses supporting FM processes in CREM. A second obstacle lies within the selection of specific BIM uses to be implemented, as insecurities about the benefit and application of BIM persist. To overcome these obstacles, this study answers the following research questions:

1. RQ 1: Which BIM uses supporting FM processes in CREM can be identified?
2. RQ 2: How do experts assess the benefit of BIM uses for FM in CREM?
3. RQ 3: How strong are the associations between each BIM use's benefit assessment and the respondents' industries?
4. RQ 4: What prioritisation for the development of BIM uses for FM in CREM can be derived from the BIM uses' benefit assessments and their association with industries?

Concerning RQ 1, a comprehensive, literature-based and expert-validated list of BIM uses for FM in CREM is provided, as shown in Table 3.

As for RQ 2, a survey with BIM-experienced CREM experts assessed each BIM use's benefit, identifying the most beneficial BIM uses for FM in CREM, as shown in Figure 7.

Furthermore, research suggests that the benefit of BIM uses is strongly influenced by the implementing organisation's industry [15,16]. RQ 3 thus analysed the associations between each BIM use's benefit assessment and respondents' industries. It showed that the benefit assessments of certain BIM uses had strong associations with the respondents' industries—namely 11 Handover and Commissioning; 21 Visualisation; 25 FM Documentation: Management and Maintenance; and 31 Space and Room Management. These results confirm the findings of Munir et al. [15] and Cavka et al. [16] highlighting the strong influence of an organisation's industry background on its BIM priorities and requirements for supporting specific FM processes. This study affirms the results by Munir et al. [17] and Cavka et al. [16] by showing that different industries assess the benefit of BIM uses for FM differently.

As the implementation of BIM for FM in CREM requires the identification of further research directions regarding the development of guides and templates, this study also aims at deriving a prioritisation for the development of BIM uses for FM in CREM by answering this study's RQ 4. As shown in Figure 9, prioritisation for the development of BIM uses for FM in CREM can be derived from each BIM use's benefit assessment in connection with its respective association with the respondents' industries. The BIM use with the highest priority for further development is 46 Facilities and Equipment: Repair and Renewal. The BIM use with the lowest priority for further development is 21 Visualisation.

The findings described above result in four implications concerning the development of BIM uses for FM in CREM:

(1) It is important to emphasise that the benefit assessments collected in this study are not or are only partly based on experience gathered during the BIM uses' implementation in reality. This means the benefit assessments rely largely on the experts' experience in the fields of BIM and FM in CREM and do, to a certain extent, reflect expectations of each BIM use's potential benefit. Therefore, further research in the form of case studies is suggested to develop and implement BIM uses under real conditions for quantifiable benefit assessments.

(2) Based on this study's results regarding the prioritisation for the development of BIM uses for FM in CREM and implication (1), further research is suggested to define information requirements for high-priority BIM uses. Since an obstacle to the implementation of BIM for FM in CREM lies within a lack of guides and templates, basic information requirements need to be identified to support the implementation of BIM in this context [10,14].

(3) An additional implication comes from the identification of technical requirements. Regarding the implementation of high-priority BIM uses within the context of FM in CREM, an investigation of the technical requirements is suggested. Given the diversity of software solutions and programmes used within CREM, further research might address questions of information exchange and data formats within this specific context.

(4) On a process and personnel level, the definition of processes and personnel activities to support the implementation of high-priority BIM uses within the context of FM in CREM is suggested as further research. This fourth implication derives from the fact that established FM processes may require the development of new processes to allow personnel to adapt the processes and personnel activities of FM tasks to the BIM-based processes and personnel activities.

9. Conclusions

The number of current state initiatives, road maps, and associations promoting the implementation of BIM illustrates the expectations it raises regarding the digitisation of the construction industry as a whole. However, most efforts and research projects still target its application in the design and construction phases. Even though buildings accumulate the largest part of their life cycle cost during their operational phase, the implementation of BIM in this life cycle phase has been investigated to a comparably small extent. Related research suggests that one of the main obstacles hampering BIM implementation in FM lies within the identification of FM processes that can be supported with BIM and the subsequent definition of information requirements. In other terms, FM professionals often do not know which FM process can or should be supported with BIM and which information a BIM should contain to do so. Due to the complexity of modern FM, professionals frequently rely on guides and templates to perform certain tasks. Currently, a lack of guides or templates for the definition of specific BIM requirements for FM has been observed. In this current state, the process of information requirement definition for FM requires deeper knowledge of BIM and active participation in the design and construction process to assure that FM requirements are sufficiently considered during these phases—prerequisites that not all FM professionals can fulfil. Given this lack of guides or templates, this study lays the ground for further research aiming at the provision of such supporting documents.

As a result, a total of 35 BIM uses were identified and defined. As related research suggests that different industries expect different benefits from BIM uses due to their specific real estate portfolios, BIM uses that benefit all industries had to be identified subsequently.

It showed that the BIM use with the highest priority for development is 46 Facilities and Equipment: Repair and Renewal whereas the BIM use with the lowest priority is 21 Visualisation. Based on the study's results, the following conclusions can be drawn:

1. Many of the FM processes from GEFMA 100-2 can be supported with BIM, opening up a multitude of application areas for BM in FM.
2. The implementation of BIM in CREM remains narrow, as the limited number of available participants illustrates.
3. High-priority BIM uses can be identified for a variety of FM main processes, namely 1 Commissioning, 4 Operations, 6 Cleaning and Maintaining, and 8 Provide Support.
4. Further research will need to develop reliable quantitative methods to measure how beneficial the implementation of a BIM use is compared to the current solutions.

The present study extends the knowledge on BIM in the context of CREM by providing a base for further research. It provides a literature-based list of potential applications of BIM for FM in CREM, opening up a variety of case studies to accelerate digitisation within this context. In order to identify further research directions with high impact, it also provides a prioritisation of BIM uses expected to generate high benefit, regardless of the industry concerned.

10. Limitations

Furthermore, the limitations of this study might also be addressed in future research:

(1) The list of BIM uses supporting FM processes in CREM may not apply in other countries as the identification of BIM uses is based on FM processes listed in the GEFMA 100-2. This is because there is no international standard defining specific FM processes. This limitation could not be overcome at this point and it may impact the studies' findings regarding the definition of the BIM uses identified. Future research could repeat the study using other national standards as a base. Alternatively, by using a yet-to-be-published international standard, further research could help to define a list of internationally acknowledged and standardised BIM uses supporting FM processes in CREM.

(2) The identification of significant relationships between industries and beneficial BIM uses may be affected by the limited sample size. Due to the two prerequisites for participating in the online survey conducted—being a CREM expert and possessing prior BIM experience—the potential number of participants was highly restricted by default. As the implementation of BIM in the field of FM, in general, and in CREM, in particular, remains narrow, this limitation could not be overcome at this point. Thus, the study's findings may be biased as several industries have not engaged in

the implementation of BIM in FM yet, exempting their perspective from the survey. This may impact the study's findings, as it may limit the extent to which they can be generalised. Further research could address this limitation by either repeating the survey as a whole or investigating specific industries individually.

Subsequent application of the proposed analysis approach for limitations (1) and (2) would allow further identification of high-priority BIM uses and BIM uses with strong associations with certain industries. Subsequently, comparisons with the results presented in this study could be conducted.

Author Contributions: Conceptualization, M.B. and C.S.; methodology, M.B. and C.S.; software, M.B.; validation, M.B. and C.S.; formal analysis, M.B. and C.S.; investigation, M.B.; resources, M.B.; data curation, M.B.; writing—original draft preparation, M.B.; writing—review and editing, M.B. and C.S.; visualization, M.B.; supervision, C.S.; project administration, C.S.; funding acquisition, M.B. All authors have read and agreed to the published version of the manuscript.

Funding: This publication was supported by the Open Access Publishing Fund of the University of Stuttgart.

Data Availability Statement: The data presented in this study is available on request from the corresponding author.

Acknowledgments: The authors would like to thank the IFMA Austria, the RealFM e.V., and the SVIT FM Schweiz for their support in survey distribution.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Identified BIM uses for FM in CREM—FM main processes, sources, and frequency.

FM Main Process	No.	BIM Use	Sources	Frequ.
1 Commissioning	11	Handover and Commissioning	[16,61–69]	10
	12	As-Built Modelling and Documentation	[18,52,61–73]	15
2 Manage Operations	21	Visualisation	[18,61–63,65–68,70,71,74]	11
	22	Disaster Planning and Emergency Preparedness	[18,19,25,55,61–66,68,70,74]	13
	23	Wayfinding and Tracking	[16,18,55,61–65]	8
	24	Generate: 2D Plans and 3D Details	[16,19,56,61–72,74]	16

Table A1. *Cont.*

FM Main Process	No.	BIM Use	Sources	Frequ.
	25	FM Documentation: Management and Maintenance	[14,16,19,52,56,61–74]	19
	26	Ticket Management	[56,61,63,68,72]	5
	27	FM Quality Management	[25]	1
	28	FM Sustainability and Environmental Protection	[19,25,62,64–67,70–72,74]	11
3 Provide Workplaces	31	Space and Room Management	[18,19,25,55,56,61–68,70–72,74]	17
	32	Relocation Management	[62,63,68]	3
	33	Equipment and Furnishing	[61,62,68,72]	4
4 Operations	41	BIM 2 Field	[52,61–63,65]	5
	42	Structural Health Monitoring	[62,63,65,67,68,71,72,74]	8
	43	Facility Identification System	[14,63,65,68,71]	5
	44	Facilities and Equipment: Periodic Inspections	[14,16,18,55,56,62,63,65,68,71,72]	11
	45	Facilities and Equipment: Inspection and Maintenance	[14,16,18,19,25,55,56,61–70,72,74]	19
	46	Facilities and Equipment: Repair and Renewal	[14,16,18,25,55,56,61–65,67–74]	19
5 Supply and Disposal	51	Real-time Acquisition and Display of Sensor Data	[18,62,63,65,68,72]	6
	52	Energy Management	[16,18,19,55,62–74]	17
	53	Waste Management	[62,68,72]	3
6 Cleaning and Maintaining	61	Cleaning Management: Maintenance Cleaning	[61,63,65,67,68,72,74]	7
	62	Cleaning Management: Glass and Facade Cleaning	[61,63,65,67,68,72,74]	7
	63	Cleaning Management: Outdoor Facilities Cleaning	[Pretest]	-
7 Asset Management	71	Security Management	[25,61,62,65,68,72]	6
	72	Locking Management	[25,61,62,65,68,72]	6
	73	Rent Management	[16,19,25,68,72]	5
	74	Generate: Inventory, Component, and Equipment Lists	[16,19,61,62,64–66,68–72,74]	13

Table A1. *Cont.*

FM Main Process	No.	BIM Use	Sources	Frequ.
	75	FM Accounting and FM Controlling	[16,18,19,25,61–63,65,68,70–74]	14
	76	Perform Contract and Insurance Management	[16,19,25,62,63,65,72]	7
	77	Defect Management	[16,19,62,63,65,68,72]	7
8 Provide Support	81	Room Booking and Occupancy Systems	[25,62,63,65,72]	5
	82	Event Planning	[62]	1
	83	Perform Procurement	[16,25,61–63,65,68,72]	8

Alshorafa and Ergen [14]; Cavka et al. [16]; Becerik-Gerber et al. [18]; McArthur and Sun [19]; Carbonari et al. [25]; Miettinen et al. [52]; Mayo and Issa [55]; Lazar and McArthur [56]; buildingSMART International [61]; Institut für Technologie und Management im Baubetrieb [62]; BIMe initiative [63]; Statsbygg [64]; Bouw Informatie Raad [65]; NATSPEC [66]; Construction Industry Council [67]; Direction générale de l'Aménagement, du Logement et de la Nature [68]; buildingSMART France [69]; College of Engineering [70]; New York City Department of Design and Construction [71]; buildingSMART Finland [72]; Building and Construction Authority [73]; AEC [74].

Table A2. Main processes' Cronbach's alpha and the arithmetic mean (AM) of each BIM uses' benefit assessment with corresponding standard deviation (ST DEV), and rank.

FM Main Process	Cronbach's Alpha	No.	BIM Use	AM	ST DEV	Rank
1 Commissioning	0.683	11	Handover and Commissioning	4.00	0.85	5
		12	As-Built Modelling and Documentation	4.35	0.68	1/2
2 Manage Operations	0.729	21	Visualisation	3.81	0.97	10
		22	Disaster Planning and Emergency Preparedness	3.51	0.99	19
		23	Wayfinding and Tracking	3.76	0.93	11
		24	Generate: 2D Plans and 3D Details	4.08	0.86	4
		25	FM Documentation: Management andMaintenance	4.35	0.75	1/2
		26	Ticket Management	3.57	1.01	17
		27	FM Quality Management	3.00	1.18	33
		28	FM Sustainability and Environmental Protection	3.46	1.17	21
3 Provide Workplaces	0.702	31	Space and Room Management	4.32	0.75	3
		32	Relocation Management	3.43	1.07	22
		33	Equipment and Furnishing	3.22	1.03	29

Table A2. *Cont.*

FM Main Process	Cronbach's Alpha	No.	BIM Use	AM	ST DEV	Rank
4 Operations	0.799	41	BIM 2 Field	3.65	1.01	14
		42	Structural Health Monitoring	3.05	1.18	32
		43	Facility Identification System	3.49	1.04	20
		44	Facilities and Equipment: Periodic Inspections	3.92	1.12	8
		45	Facilities and Equipment: Inspection andMaintenance	3.97	1.04	6
		46	Facilities and Equipment: Repair and Renewal	3.95	1.10	7
5 Supply and Disposal	0.716	51	Real-time Acquisition and Display of Sensor Data	3.41	1.07	23
		52	Energy Management	3.73	1.07	12
		53	Waste Management	3.11	1.07	31
6 Cleaning and Maintaining	0.932	61	Cleaning Management: Maintenance Cleaning	3.70	1.02	13
		62	Cleaning Management: Glass and FacadeCleaning	3.62	1.04	15
		63	Cleaning Management: Outdoor Facilities Cleaning	3.32	1.18	25
7 Asset Management	0.841	71	Security Management	3.14	1.08	30
		72	Locking Management	3.30	1.02	26
		73	Rent Management	3.27	1.02	27
		74	Generate: Inventory, Component, and Equipment Lists	3.89	0.81	9
		75	FM Accounting and FM Controlling	3.35	1.01	24
		76	Perform Contract and Insurance Management	2.70	1.00	35
		77	Defect Management	3.59	1.04	16
8 Provide Support	0.734	81	Room Booking and Occupancy Systems	3.54	1.04	18
		82	Event Planning	2.89	1.07	34
		83	Perform Procurement	3.24	1.09	28

References

1. European Construction Sector Observatory. Digitalisation in the Construction Sector: Analytical Report. Available online: https://ec.europa.eu/docsroom/documents/45547 (accessed on 2 August 2021).
2. Sigalov, K.; Ye, X.; König, M.; Hagedorn, P.; Blum, F.; Severin, B.; Hettmer, M.; Hückinghaus, P.; Wölkerling, J.; Groß, D. Automated Payment and Contract Management in the Construction Industry by Integrating Building Information Modeling and Blockchain-Based Smart Contracts. *Appl. Sci.* **2021**, *11*, 7653. [CrossRef]
3. Daniotti, B.; Pavan, A.; Lupica Spagnolo, S.; Caffi, V.; Pasini, D.; Mirarchi, C. *BIM-Based Collaborative Building Process Management*; Springer International Publishing: Cham, Switzerland, 2020; ISBN 978-3-030-32888-7.
4. McKinsey & Company. Imagining Construction's Digital Future. Available online: https://www.mckinsey.com/business-functions/operations/our-insights/imagining-constructions-digital-future (accessed on 2 August 2021).
5. EU BIM Task Group. Handbook for the Introduction of Building Information Modelling by the European Public Sector: Strategic action for Construction Sector Performance: Driving Value, Innovation and Growth. Available online: http://www.eubim.eu/handbook-selection/ (accessed on 2 August 2021).
6. Gerbert, P.; Castagnino, S.; Rothballer, H.; Re, A.; Filitz, R. The Transformative Power of Building Information Modeling: Digital in Engineering and Construction. Available online: https://www.bcg.com/de-de/publications/2016/engineered-products-infrastructure-digital-transformative-power-building-information-modeling (accessed on 2 August 2021).
7. Lewis, A.; Riley, D.; Elmualim, A. Defining High Performance Buildings for Operations and Maintenance. *IJFM* **2010**, *1*, 1–16.
8. Pfnür, A. Volkswirtschaftliche Bedeutung von Corporate Real Estate in Deutschland. Available online: https://www.aurelis-real-estate.de/fileadmin/user_upload/Bilder/News/Studien/Studie_CREM.pdf (accessed on 15 February 2021).
9. Scarponcini, P. Editorial: Time for an Integrated Approach to Facility Management. *JCCE* **1996**, *10*, 1. [CrossRef]
10. Edirisinghe, R.; London, K.A.; Kalutara, P.; Aranda-Mena, G. Building information modelling for facility management: Are we there yet? *ECAM* **2017**, *24*, 1119–1154. [CrossRef]
11. Glatte, T. *Corporate Real Estate Management*; Springer Fachmedien Wiesbaden: Wiesbaden, Germany, 2021; ISBN 978-3-658-32221-2.
12. Heywood, C.; Kenley, R. Five axioms for corporate real estate management: A polemical review of the literature. In Proceedings of the PRRES Conference—2013, Melbourne, Australia, 13–16 January 2013.
13. Wilkinson, S.J.; Jupp, J.R. Exploring the value of BIM for corporate real estate. *JCRE* **2016**, *18*, 254–269. [CrossRef]
14. Alshorafa, R.; Ergen, E. Identification of information requirements for implementing Building Information Modeling based on model uses. *ITcon* **2020**, *25*, 561–574. [CrossRef]
15. Munir, M.; Kiviniemi, A.; Jones, S.W. Business value of integrated BIM-based asset management. *ECAM* **2019**, *26*, 1171–1191. [CrossRef]
16. Cavka, H.B.; Staub-French, S.; Poirier, E.A. Developing owner information requirements for BIM-enabled project delivery and asset management. *AIC* **2017**, *83*, 169–183. [CrossRef]
17. Munir, M.; Kiviniemi, A.; Jones, S.; Finnegan, S. BIM-based operational information requirements for asset owners. *AEDM* **2020**, *16*, 100–114. [CrossRef]
18. Becerik-Gerber, B.; Jazizadeh, F.; Li, N.; Calis, G. Application Areas and Data Requirements for BIM-Enabled Facilities Management. *JCEM* **2012**, *138*, 431–442. [CrossRef]
19. McArthur, J.J.; Sun, X. Best practices for BIM Execution Plan development for a Public–Private Partnership Design-Build-Finance-Operate-Maintain project. In *Building Information Modelling (BIM) in Design, Construction and Operations*; BIM 2015; Mahdjoubi, L., Brebbia, C.A., Laing, R., Eds.; WIT Press: Southampton, UK, 2015; pp. 119–130.
20. Sarstedt, M.; Mooi, E. *A Concise Guide to Market Research*; Springer: Berlin/Heidelberg, Germany, 2019; ISBN 978-3-662-56706-7.
21. Casula, M.; Rangarajan, N.; Shields, P. The potential of working hypotheses for deductive exploratory research. *Qual. Quant.* **2020**, *55*, 1703–1725. [CrossRef] [PubMed]
22. McGraw Hill Construction Research & Analytics. The Business Value of BIM for Construction in Global Markets: How Contractors Around the World Are Driving Innovation with Building Information Modeling. Available online: https://www.construction.com/toolkit/reports/bim-business-value-construction-global-markets (accessed on 22 March 2022).
23. Construction IT Alliance Limited. BICP Global BIM Study: Lessons for Ireland's BIM Programme. Available online: http://www.bicp.ie/bicp-global-bim-study (accessed on 21 July 2021).
24. German Facility Management Association e.V. *Facility Management: Leistungsspektrum*; German Facility Management Association: Berlin, Germany, 2004.
25. Carbonari, G.; Stravoravdis, S.; Gausden, C. Improving FM task efficiency through BIM: A proposal for BIM implementation. *JCRE* **2018**, *20*, 4–15. [CrossRef]
26. Campanelli, P. Testing survey questions. In *International Handbook of Survey Methodology*; Online-Ausgabe; de Leeuw, E.D., Hox, J.J., Dillman, D., Eds.; Taylor and Francis: Florence, Italy, 2008; pp. 176–200. ISBN 9780203843123.
27. Stockemer, D. *Quantitative Methods for the Social Sciences*; Springer International Publishing: Cham, Switzerland, 2019; ISBN 978-3-319-99117-7.
28. European Commission. *NACE Rev. 2: Statistical Classification of Economic Activities in the European Community*; Office for Official Publications of the European Communities: Luxemburg, 2008; ISBN 9789279047411.
29. Love, P.E.; Matthews, J.; Simpson, I.; Hill, A.; Olatunji, O.A. A benefits realization management building information modeling framework for asset owners. *AIC* **2014**, *37*, 1–10. [CrossRef]

30. Hox, J.J. Accommodating measurement errors. In *International Handbook of Survey Methodology*; Online-Ausgabe; de Leeuw, E.D., Hox, J.J., Dillman, D., Eds.; Taylor and Francis: Florence, Italy, 2008; pp. 387–402. ISBN 9780203843123.
31. Scott Jones, J. Learn to Use the Eta Coefficient Test in R with Data from the NIOSH Quality of Worklife Survey. 2014. Available online: https://methods.sagepub.com/dataset/eta-coefficient-niosh-qwl-2014?fromsearch=true (accessed on 20 December 2021).
32. Krumm, P.J. History of real estate management from a corporate perspective. *Facilities* **2001**, *19*, 276–286. [CrossRef]
33. Jalil Omar, A.; Heywood, C.A. Defining a corporate real estate management's (CREM) brand. *JCRE* **2014**, *16*, 60–76. [CrossRef]
34. van der Voordt, T. Facilities management and corporate real estate management: FM/CREM or FREM? *JFM* **2017**, *15*, 244–261. [CrossRef]
35. Redlein, A. *Modern Facility and Workplace Management*; Springer International Publishing: Cham, Switzerland, 2020; ISBN 978-3-030-35313-1.
36. International Organisation for Standardisation. *Facility Management—Vocabulary*; International Organisation for Standardisation (ISO): Geneva, Switzerland, 2017.
37. Kassem, M.; Kelly, G.; Dawood, N.; Serginson, M.; Lockley, S. BIM in facilities management applications: A case study of a large university complex. *Built Environ. Proj. Asset Manag.* **2015**, *5*, 261–277. [CrossRef]
38. Carbonari, G.; Ashworth, S.; Stravoravdis, S. How facility management can use building information modelling (BIM) to improve the decision making process. *JfFM* **2015**, *10*, 55–69.
39. Eadie, R.; Browne, M.; Odeyinka, H.; McKeown, C.; McNiff, S. BIM implementation throughout the UK construction project lifecycle: An analysis. *AIC* **2013**, *36*, 145–151. [CrossRef]
40. Pärn, E.A.; Edwards, D.J.; Sing, M. The building information modelling trajectory in facilities management: A review. *AIC* **2017**, *75*, 45–55. [CrossRef]
41. Evjen, T.Å.; Raviz, S.R.H.; Petersen, S.A. Enterprise BIM: A Holistic Approach to the Future of Smart Buildings. In *REAL CORP 2020: Shaping Urban Change—Livable City Regions for the 21st Century, Proceedings of the 25th International Conference on Urban Planning, Regional Development and Information Society, Virtual Conference, 15–18 September 2020*; Schrenk, M., Popovich, V.V., Zeile, P., Elisei, P., Beyer, C., Ryser, J., Reicher, C., Çelik, C., Eds.; Schrenk, M., Popovich, V.V., Zeile, P., Elisei, P., Beyer, C., Ryser, J., Reicher, C., Çelik, C., Eds.; CORP-Competence Center of Urban and Regional Planning: Wien, Österreich, 2020; pp. 251–260.
42. McGraw Hill Construction Research & Analytics. Measuring the Impact of BIM on Complex Buildings. Available online: https://www.construction.com/toolkit/reports/measuring-impact-bim-complex-buildings (accessed on 22 March 2022).
43. Terreno, S.; Asadi, S.; Anumba, C. An Exploration of Synergies between Lean Concepts and BIM in FM: A Review and Directions for Future Research. *Buildings* **2019**, *9*, 147. [CrossRef]
44. BuildingSMART Alliance. National BIM Standard—United States®Version 3–5.7 BIM Planning Guide for Facility Owners, Version 2.0—June 2013. Available online: https://www.nationalbimstandard.org/nbims-us (accessed on 30 April 2021).
45. Wijekoon, C.; Manewa, A.; Ross, A.D. Enhancing the value of facilities information management (FIM) through BIM integration. *ECAM* **2018**, *27*, 809–824. [CrossRef]
46. Messner, J.; Anumba, C.; Dubler, C.; Goodman, S.; Kasprzak, C.; Kreider, R.; Leicht, R.; Saluja, C.; Zikic, N. BIM Project Execution Planning Guide—Version 2.2. Available online: https://bim.psu.edu/ (accessed on 3 February 2021).
47. Godager, B.; Onstein, E.; Huang, L. The Concept of Enterprise BIM: Current Research Practice and Future Trends. *IEEE Access* **2021**, *9*, 42265–42290. [CrossRef]
48. Jupp, J.; Awad, R. BIM-FM and Information Requirements Management: Missing Links in the AEC and FM Interface. In Proceedings of the 14th IFIP International Conference on Product Lifecycle Management (PLM), Seville, Spain, 10–12 July 2017; Ríos, J., Bernard, A., Bouras, A., Foufou, S., Eds.; Springer International Publishing: Cham, Switzerland, 2017; pp. 311–316, ISBN 978-3-319-72904-6.
49. Lin, Y.-C.; Chen, Y.-P.; Huang, W.-T.; Hong, C.-C. Development of BIM Execution Plan for BIM Model Management during the Pre-Operation Phase: A Case Study. *Buildings* **2016**, *6*, 8. [CrossRef]
50. Bähre, B. Building Information Modeling: The 'C' in BIM. In *Informed Architecture*; Hemmerling, M., Cocchiarella, L., Eds.; Springer International Publishing: Cham, Switzerland, 2018; pp. 39–52. ISBN 978-3-319-53134-2.
51. Ashworth, S.; Tucker, M. FM Awareness of Building Information Modelling (BIM). Available online: https://www.iwfm.org.uk/resource/fm-awareness-of-bim.html (accessed on 15 July 2021).
52. Miettinen, R.; Kerosuo, H.; Metsälä, T.; Paavola, S. Bridging the life cycle: A case study on facility management infrastructures and uses of BIM. *JFM* **2018**, *16*, 2–16. [CrossRef]
53. Deutsches Institut für Normung e.V. Deutsche Normungsroadmap BIM: Version 1. Available online: https://www.din.de/de/din-und-seine-partner/presse/mitteilungen/breite-anwendung-von-bim-foerdern-847244 (accessed on 16 December 2021).
54. Hilal, M.A.; Maqsood, T.; Abdekhodaee, A. A scientometric analysis of BIM studies in facilities management. *IJBPA* **2019**, *37*, 122–139. [CrossRef]
55. Mayo, G.; Issa, R.R.A. Nongeometric Building Information Needs Assessment for Facilities Management. *JME* **2016**, *32*, 4015054. [CrossRef]
56. Lazar, S.; McArthur, J.J. BIM for Corporate Real Estate Data Visualization from Disparate Systems. In *Smart City 360°*; Leon-Garcia, A., Lenort, R., Holman, D., Staš, D., Krutilova, V., Wicher, P., Cagáňová, D., Špirková, D., Golej, J., Nguyen, K., Eds.; Springer International Publishing: Cham, Switzerland, 2016; pp. 504–516. ISBN 978-3-319-33680-0.

57. Taber, K.S. The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education. *Res. Sci. Educ.* **2018**, *48*, 1273–1296. [CrossRef]
58. Triantaphyllou, E.; Mann, S.H. An examination of the effectiveness of multi-dimensional decision-making methods: A decision-making paradox. *Decis. Support Syst.* **1989**, *5*, 303–312. [CrossRef]
59. Tofallis, C. Add or Multiply? A Tutorial on Ranking and Choosing with Multiple Criteria. *INFORMS Trans. Educ.* **2014**, *14*, 109–119. [CrossRef]
60. Fang, Z.; Liu, Y.; Lu, Q.; Pitt, M.; Hanna, S.; Tian, Z. BIM-integrated portfolio-based strategic asset data quality management. *AIC* **2022**, *134*, 104070. [CrossRef]
61. BuildingSMART International. Use Case Documentation. Available online: https://www.buildingsmart.org/wp-content/uploads/2019/02/bSI-Awards-2019-Use-Case-Documentation-V4-1.xlsx (accessed on 1 June 2021).
62. Institut für Technologie und Management im Baubetrieb. Katalog der BIM-Anwendungsfälle. Available online: https://www.tmb.kit.edu/download/Katalog_der_BIM-Anwendungsfaelle.pdf (accessed on 17 March 2021).
63. BIMe Initiative. BIMe Initiative Model Uses List. Available online: https://bimexcellence.org/resources/200series/211in/ (accessed on 1 June 2021).
64. Statsbygg. Statsbygg Building Information Modelling Manual. *Version 1.2.1.* Available online: www.statsbygg.no/bim (accessed on 1 June 2021).
65. Bouw Informatie Raad. Poster BIM Uses. Available online: https://www.bouwinformatieraad.nl/main.php?mode=download_cat&cat_id=10 (accessed on 2 June 2021).
66. NATSPEC. NATSPEC National BIM Guide. Available online: https://bim.natspec.org/documents/natspec-national-bim-guide (accessed on 8 June 2021).
67. Construction Industry Council. CIC BIM Standards General Version 2. Available online: https://www.bim.cic.hk/en/resources/publications?cate=48 (accessed on 9 June 2021).
68. Direction générale de l'Aménagement, du Logement et de la Nature. Plan BIM 2022. Available online: https://www.cohesion-territoires.gouv.fr/sites/default/files/2019-07/Plan%20BIM%202022.pdf (accessed on 21 April 2021).
69. BuildingSMART France. Guide: Comment Rédiger Une Convention BIM? Available online: https://buildingsmartfrance-mediaconstruct.fr/memos-pratiques-BIM/ (accessed on 11 May 2021).
70. College of Engineering. BIM Uses. Available online: https://bim.psu.edu/uses/ (accessed on 1 June 2021).
71. New York City Department of Design and Construction. BIM Guidelines. Available online: https://www1.nyc.gov/site/ddc/resources/publications.page (accessed on 2 June 2021).
72. buildingSMART Finland. COBIM Common BIM Requirements: Series 12 Use of Models in Facility Management. Available online: https://buildingsmart.fi/en/common-bim-requirements-2012/ (accessed on 7 June 2021).
73. Building and Construction Authority. Singapore BIM Guide Version 2. Available online: https://www.corenet.gov.sg/media/586132/Singapore-BIM-Guide_V2.pdf (accessed on 7 June 2021).
74. AEC. AEC (UK) BIM Protocol Project BIM Execution Plan. Available online: https://aecuk.wordpress.com/documents/ (accessed on 8 February 2022).

Article 2

Developments in the Built Environment 16 (2023) 100224

Contents lists available at ScienceDirect

Developments in the Built Environment

journal homepage: www.sciencedirect.com/journal/developments-in-the-built-environment

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

Maximilian Benn *, Christian Stoy

Institute for Construction Economics, University of Stuttgart, Keplerstrasse 11, 70174, Stuttgart, Germany

ARTICLE INFO

Keywords:
Asset information requirements
Building information modelling
Corporate real estate management
Facility management
Facility services
Chemical industry

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

* Corresponding author.
E-mail addresses: maximilian.benn@bauoek.uni-stuttgart.de (M. Benn), info@bauoek.uni-stuttgart.de (C. Stoy).

https://doi.org/10.1016/j.dibe.2023.100224
Received 16 March 2023; Received in revised form 3 August 2023; Accepted 1 September 2023
Available online 9 September 2023

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

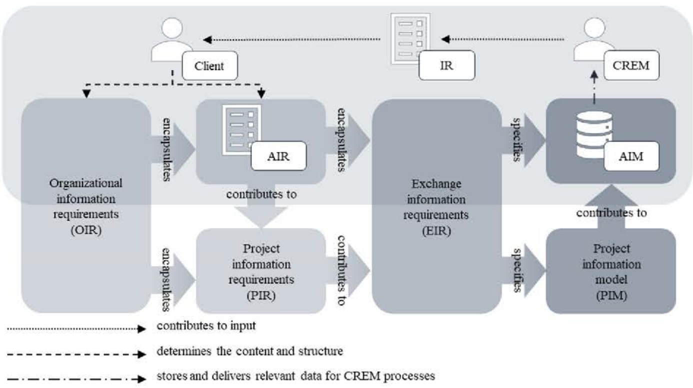


Fig. 1. Progression of information requirements based on ISO 19650–3, illustrating the flow of information requirements (IR) from CREM to the client to be included in the AIR and, ultimately, handed over in the AIM.

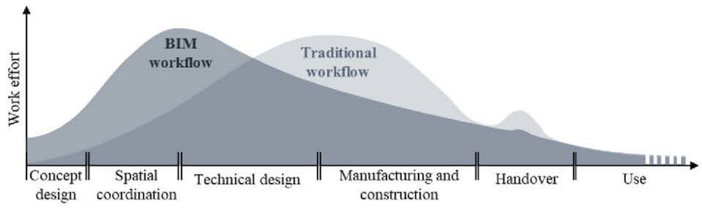


Fig. 2. Effort distribution over the life cycle phases in the traditional workflow compared to the BIM workflow.

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

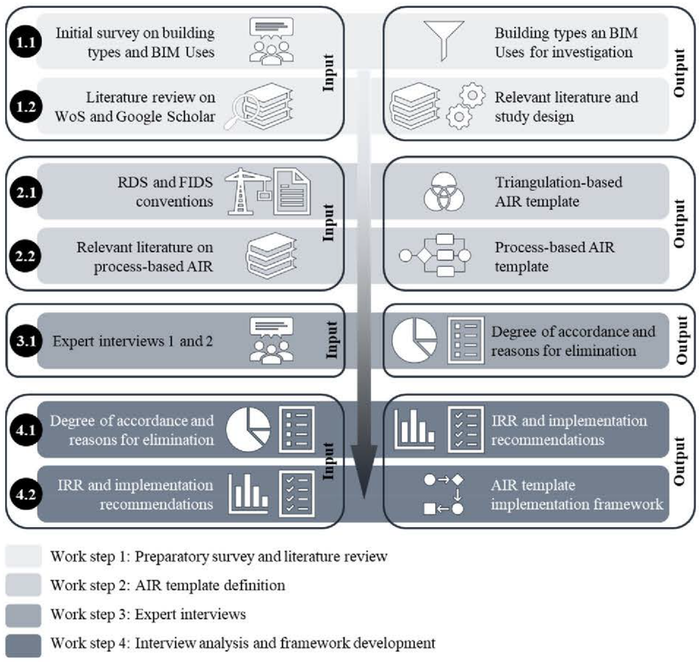


Fig. 3. Work steps of the methodology.

"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.

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.

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

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-

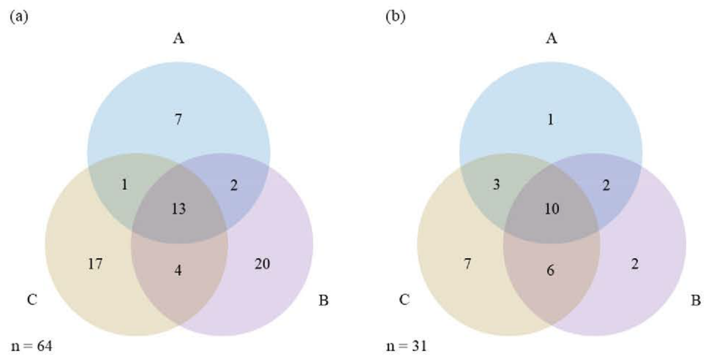


Fig. 4. Venn diagrams of the BIM Uses (a) “Space and room management” and (b) “Facility identification system for technical building services” based on RDS and FIDS conventions provided by the participating organisations.

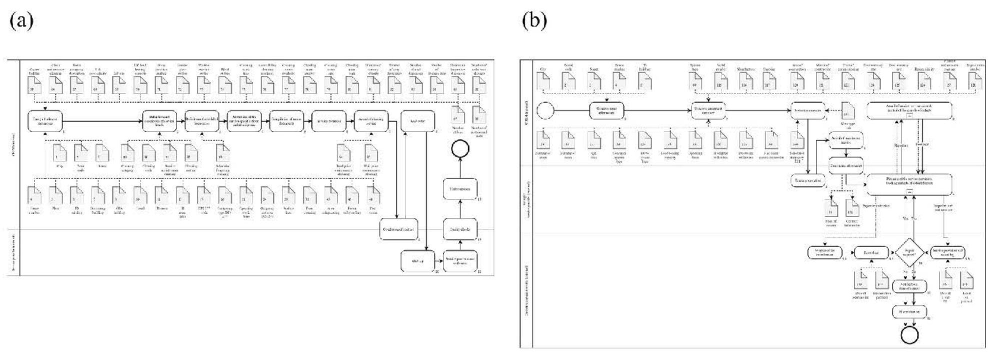


Fig. 5. Process diagrams of the BIM Uses (a) “Maintenance cleaning management” and (b) “Expert examination, inspection, and maintenance of conveyor systems”. Please see Fig. 11 and 12 in the appendix for higher resolution.

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:

$$\kappa = \frac{\overline{P} - \overline{P_e}}{1 - \overline{P_e}} \quad (1)$$

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

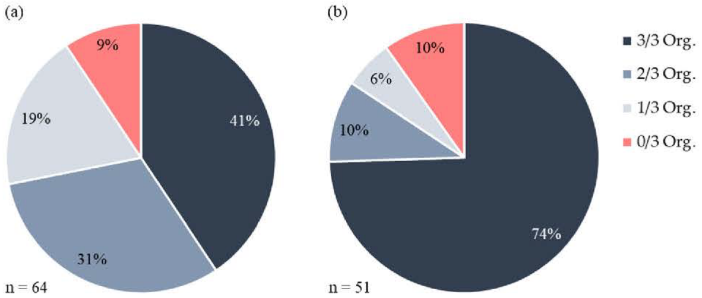


Fig. 6. Degrees of accordance of the AIR templates for (a) "Space and room management" and (b) "Maintenance cleaning management" based on interview 1.

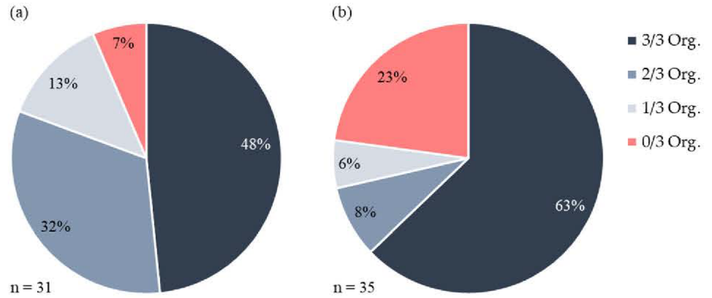


Fig. 7. Degrees of accordance of the AIR templates for (a) "Facility identification system for technical building services" and (b) "Expert examination, inspection, and maintenance of conveyor systems" based on interview 2.

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

$$\overline{P} = \frac{1}{N}\sum_{i=1}^{N} P_i \quad (4)$$

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

$\overline{P}$ 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.

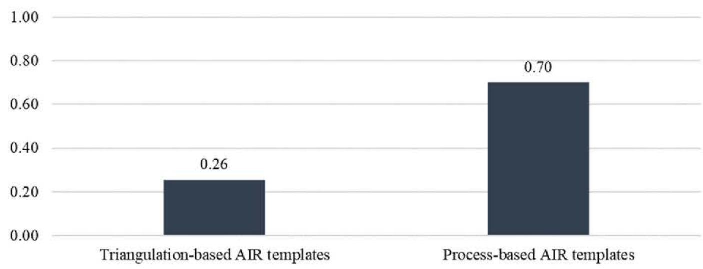


Fig. 8. Fleiss' Kappa of the triangulation-based and the process-based AIR templates based on the results of interviews 1 and 2.

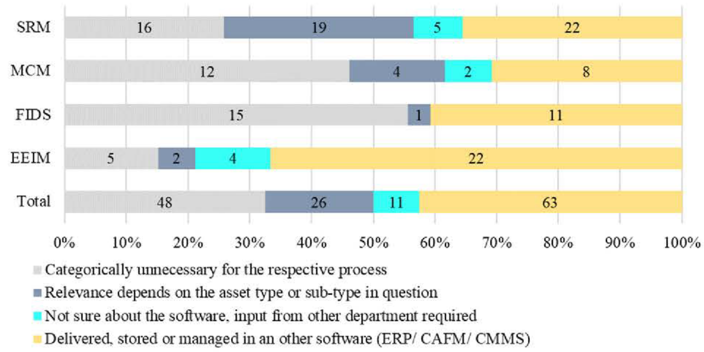


Fig. 9. Mentions of the reasons for the elimination of information requirements in proportion based on the AIR templates for the BIM Uses "Space and room management" (SRM); "Maintenance cleaning management" (MCM); "Facility identification system for technical building services" (FIDS); "Expert examination,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

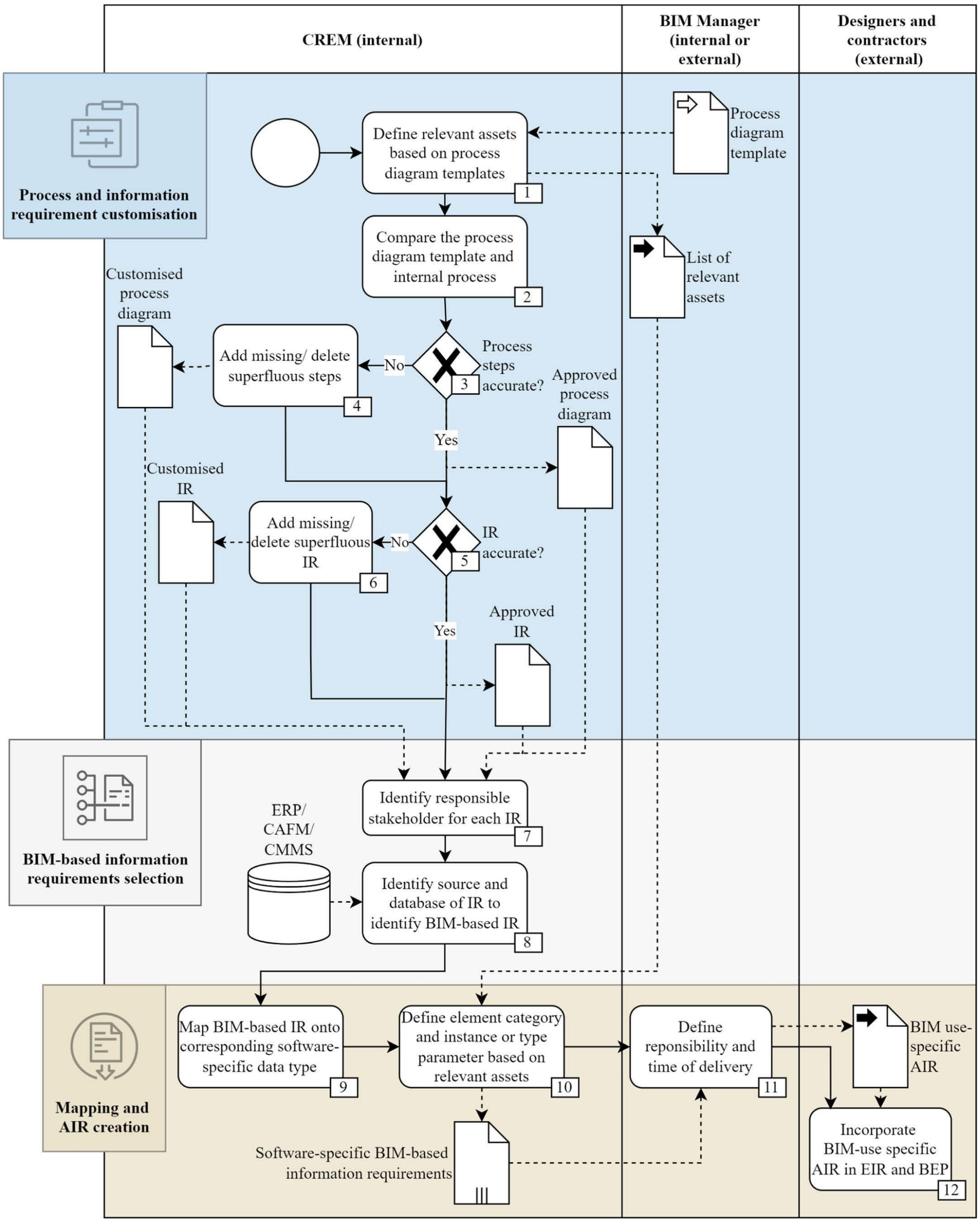


Fig. 10. User-centric AIR template implementation framework for CREM in the chemical industry.

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.

Funding

This publication was supported by the Open Access Publishing Fund of the University of Stuttgart.

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).

		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
#	Information requirement	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

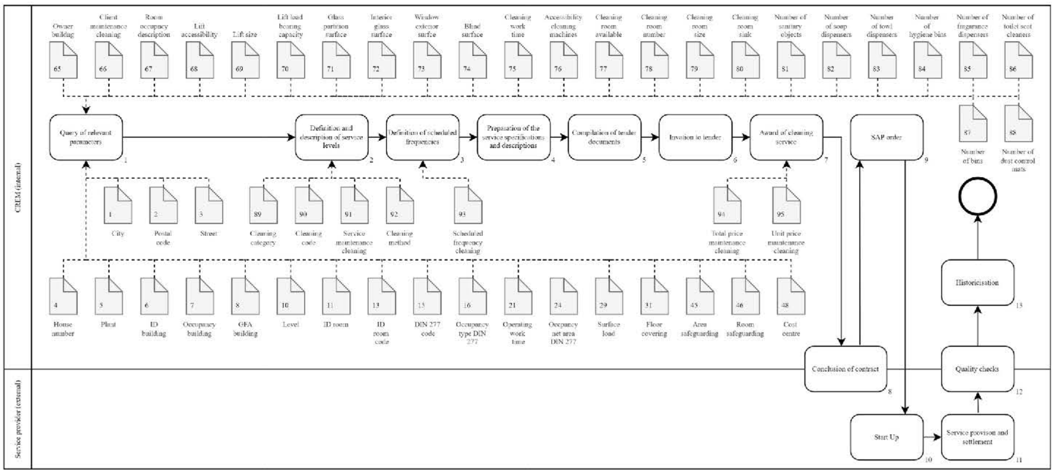


Fig. 11. Process diagram of the BIM Use "Maintenance cleaning management".

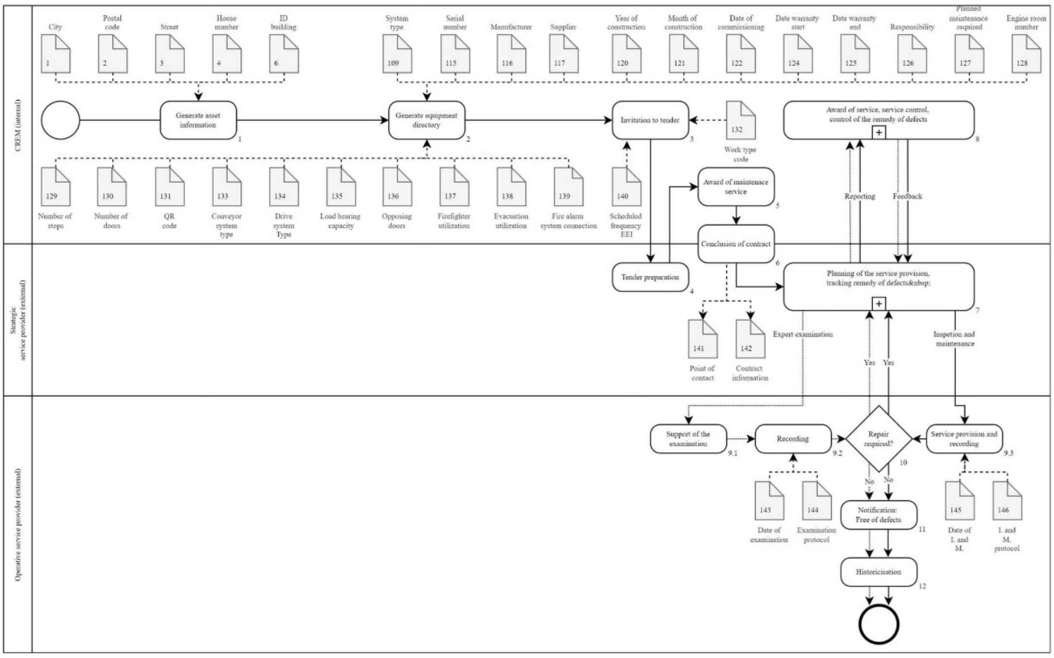


Fig. 12. Process diagram of the BIM Use "Expert examination, inspection, and maintenance of conveyor systems".

References

Abideen, D.K., Yunusa-Kaltungo, A., Manu, P., Cheung, C., 2022. A systematic review of the extent to which BIM is integrated into operation and maintenance. Sustainability 14 (14), 8692.

Agung, F.Y., Siahaan, A., 2020. Overall equipment effectiveness (OEE) through total productive maintenance (TPM) practices: a case study in chemical industry. IJEMBM 7 (1), 23–36.

Alshorafa, R., Ergen, E., 2020. Identification of information requirements for implementing Building Information Modeling based on model uses. ITcon 25, 561–574.

Ashworth, S., Druhmann, C.K., Tucker, M., 2017. Employer's Information Requirements (EIR): a BIM case study to meet client and facility manager needs. In: Balslev Nielsen, S., Jensen, P.A., Brinkø, R. (Eds.), Research Papers for EuroFM's 16th Research Symposium EFMC 2017. Polyteknisk Forlag, Lyngby, Denmark.

Ashworth, S., Tucker, M., Druhmann, C.K., 2019, 1/2. Critical success factors for facility management employer's information requirements (EIR) for BIM. F, 37, pp. 103–118.

Bartels, N., 2020. Strukturmodell zum Datenaustausch im Facility Management. Springer Fachmedien Wiesbaden, Dresden, Germany, p. 336.

Benn, M., Stoy, C., 2022. BIM for CREM: exploring the benefit of building information modelling for facility management in corporate real estate management. Buildings 12 (4), 400.

BIMe initiative, 2023. Model Use Templates. https://bimexcellence.org/projects/integrated-information-project/model-use-templates/;. (Accessed 7 February 2023).

Blackburn, R., Lurz, K., Priese, B., Göb, R., Darkow, I.-L., 2015. A predictive analytics approach for demand forecasting in the process industry. Int. Trans. Oper. Res. 22 (3), 407–428.

Braun, B., Dessauer, M., Henderson, K., Peng, Y., Seasholtz, M.B., 2022. Methodology to screen vendors for predictive maintenance in the chemical industry. J. Adv. Manuf. Process 4 (1).

buildingSMART, Finland, 2012. COBIM Common BIM Requirements. https://buildingsmart.fi/en/common-bim-requirements-2012/;. (Accessed 7 June 2021).

buildingSMART Alliance, 2013. National BIM Standard - United States® Version 3 - 5.7 BIM Planning Guide for Facility Owners. Version 2.0 – June 2013. https://www.nationalbimstandard.org/nbims-us;. (Accessed 30 April 2021).

buildingSMART International, 2023. Use Case Management. https://ucm.buildingsmart.org/;. (Accessed 7 February 2023).

Cavka, H.B., Staub-French, S., Poirier, E.A., 2017. Developing owner information requirements for BIM-enabled project delivery and asset management. AIC 83, 169–183.

Chen, Y.-R., Tserng, H.P., 2017. An integrated methodology for construction BIM & ERP by using UML tool. In: Cheng, M.-Y., Chen, H.-M., Chiu, K.C. (Eds.), Proceedings of the 34th International Symposium on Automation and Robotics in Construction (ISARC). Proceedings of the International Symposium on Automation and Robotics in Construction (IAARC). Tribun EU, s.r.o., Brno.

Chin, H.H., Varbanova, P.S., Klemes, J.J., Benjamin, M.F.D., Tan, R.R., 2020. Asset maintenance optimisation approaches in the chemical and process industries - a review. Chem. Eng. Res. Des. 164, 162–194.

College of Engineering, 2021. BIM Uses. https://bim.psu.edu/uses/;. (Accessed 1 June 2021).

Construction Industry Council, 2020. CIC BIM Standards General Version 2. https://www.bim.cic.hk/en/resources/publications?cate=48;. (Accessed 9 June 2021).

Daniotti, B., Pavan, A., Lupica Spagnolo, S., Caffi, V., Pasini, D., Mirarchi, C., 2020. BIM-based Collaborative Building Process Management. Springer International Publishing, Cham, Switzerland, p. 192.

Deloitte Development, 2017. Chemistry 4.0. https://www.vci.de/vci-online/services/publikationen/broschueren-faltblaetter/vci-deloitte-study-chemistry-4-dot-0-short-version.jsp;. (Accessed 28 July 2023).

Demirdöğen, G., Işık, Z., Arayici, Y., 2020. Lean management framework for healthcare facilities integrating BIM, BEPS and big data analytics. Sustainability 12 (17), 7061.

Deutsches Institut für Normung, e.V., 2021. Deutsche Normungsroadmap BIM. https://www.din.de/de/din-und-seine-partner/presse/mitteilungen/breite-anwendung-von-bim-foerdern-847244;. (Accessed 16 December 2021).

Dias, P.D.R., Ergan, S., 2020. Owner requirements in as-built BIM deliverables and a system architecture for FM-specific BIM representation. Can. J. Civ. Eng. 47 (2), 215–227.

Dixit, M.K., Venkatraj, V., Ostadalimakhmalbaf, M., Pariafsai, F., Lavy, S., 2019. Integration of facility management and building information modeling (BIM). F, 37, pp. 455–483, 7/8.

EU BIM Task Group, 2018. Handbook for the Introduction of Building Information Modelling by the European Public Sector. http://www.eubim.eu/handbook-selection/;. (Accessed 2 August 2021).

European Commission, 2008. NACE Rev. 2. Office for Official Publications of the European Communities, Luxembourg, Luxembourg, p. 369.

European Construction Sector Observatory, 2021. Digitalisation in the Construction Sector. https://ec.europa.eu/docsroom/documents/45547;. (Accessed 2 August 2021).
Européen de Normalisation, Comité, 2011. Facility Management - Part 4: Taxonomy, Classification and Structures in Facility Management, vol. 8. Brussels, Belgium.
Feller, D.J., 2020a. Reinigungsmanagement - Endbericht. https://biminstitut.uni-wuppertal.de/de/forschung/download-bereich/bim-anwendungsfall.html;. (Accessed 23 February 2022).
Feller, D.J., 2020b. Sachverständigen-Prüfung - Endbericht. https://biminstitut.uni-wuppertal.de/de/forschung/download-bereich/bim-anwendungsfall.html;. (Accessed 5 April 2022).
Fleiss, J.L., 1971. Measuring nominal scale agreement among many raters. Psychol. Bull. 76 (5), 378–382.
Flick, U., 2018. The SAGE handbook of qualitative data collection. https://sk.sagepub.com/reference/the-sage-handbook-of-qualitative-data-collection/i3530.xml?term=Triangulation;. (Accessed 24 January 2023).
Gerbert, P., Castagnino, S., Rothballer, h, Re, A., Filitz, R., 2016. The Transformative Power of Building Information Modeling. https://www.bcg.com/de-de/publications/2016/engineered-products-infrastructure-digital-transformative-power-building-information-modeling;. (Accessed 2 August 2021).
Glatte, T., 2021. Corporate Real Estate Management. Springer Fachmedien Wiesbaden, Wiesbaden, Germany, p. 59.
Global, CoreNet, 2022. About Cornet Global. https://en.wikipedia.org/wiki/CoreNet_Global;. (Accessed 4 May 2022).
Godager, B., Onstein, E., Huang, L., 2021. The concept of enterprise BIM: current research practice and future trends. IEEE Access 9, 42265–42290.
Gwet, K.L., 2014. Handbook of Inter-rater Reliability. Advances Analytics LLC, Gaithersburg, MD, USA, p. 410.
Helmus, M., Meins-Becker, A., Kelm, A., Damerau, N., Kaufhold, M., Feller, D.J., et al., 2019. Detaillierte Entwicklung von BIM-basierten Prozessen des Betreibens von Bauwerken zur Integration in eine lebenszyklusübergreifende Prozesskette. https://biminstitut.uni-wuppertal.de/fileadmin/biminstitut/Download-Bereich/Forschungsprojekte-_BIM-basiertes_Betreiben/Fachbericht_-_BIM-basiertes_Betreiben.pdf;. (Accessed 9 February 2021).
Hewavitharana, F.S.T., Perera, A.A.D.A.J., 2020. Sustainability via ERP and BIM integration. In: Dissanayake, R. (Ed.), Icsbe 2018. Lecture Notes in Civil Engineering Ser. v.44. Springer Singapore Pte. Limited, Singapore, pp. 202–210.
Heywood, C., Kenley, R., 2013. Five axioms for corporate real estate management: a polemical review of the literature. In: Proceedings from the PRRES Conference, 2013.
International Organisation for Standardisation, 2017. Facility Management. International Organisation for Standardisation (ISO), Geneva, Switzerland, p. 24.
International Organisation for Standardisation, 2018. Organization and Digitization of Information about Buildings and Civil Engineering Works, Including Building Information Modelling (BIM) — Information Management Using Building Information Modelling — Part 1: Concepts and Principles. International Organisation for Standardisation (ISO), Geneva, Switzerland, p. 44.
International Organisation for Standardisation, 2021. Information Management & Decision-Making Criteria. https://theiam.org/media/3118/tc251-ahg4-final-report.pdf;. (Accessed 15 November 2022).
Krumm, P.J., 2001. History of real estate management from a corporate perspective. Facilities 19 (7/8), 276–286.
Landis, J.R., Koch, G.G., 1977. The measurement of observer agreement for categorical data. Biometrics 33, 159–174.
Lewis, A., Riley, D., Elmualim, A., 2010. Defining high performance buildings for operations and maintenance. IJFM 1 (2).
Leygonie, R., Motamedi, A., Iordanova, I., 2022. Development of quality improvement procedures and tools for facility management BIM. Dev. Built Environ. 11, 100075.
Li, Y., Zhang, S., 2022. Applied Research Methods in Urban and Regional Planning. Springer International Publishing, Cham, Switzerland, p. 368.
Little, A.D., Samoylova, M., Wilmet, S., Witthaut, D., Kolk, M., 2023. Digital Technologies for Sustainability in the European Chemical Industry. https://cefic.org/library-item/digital-technologies-for-sustainability-in-the-european-chemical-industry. (Accessed 28 July 2023).
Matarneh, S.T., Danso-Amoako, M., Al-Bizri, S., Gaterell, M., Matarneh, R., 2019a. Building information modeling for facilities management: a literature review and future research directions. JBE 24.
Matarneh, S.T., Danso-Amoako, M., Al-Bizri, S., Gaterell, M., Matarneh, R.T., 2019b. BIM for FM. F 38 (5/6), 378–394.
Mayo, G., Issa, R.R.A., 2016. Nongeometric building information needs assessment for facilities management. JME 32 (3), 4015054.
Messner, J., Anumba, C., Dubler, C., Goodman, S., Kasprzak, C., Kreider, R., et al., 2019. BIM Project Execution Planning Guide - Version 2.2. https://bim.psu.edu/;. (Accessed 3 February 2021).
Munir, M., Kiviniemi, A., Jones, S., Finnegan, S., 2020. BIM-based operational information requirements for asset owners. AEDM 16 (2), 100–114.
Nojedehi, P., O'Brien, W., Gunay, H.B., 2022. A methodology to integrate maintenance management systems and BIM to improve building management. Sci. Technol. Built Environ. 1–18.
OECD, 2023. Enterprises by business size (indicator). https://data.oecd.org/entrepreneur/enterprises-by-business-size.htm. (Accessed 2 May 2023).
Pasini, D., Caffi, V., Daniotti, B., Lupica Spagnolo, S., Pavan, A., 2017. The INNOVance BIM library approach. Innov. Infrastruct. Solut. 2 (1).
Sacks, R., Girolami, M., Brilakis, I., 2020. Building information modelling, artificial intelligence and construction tech. Dev. Built Environ. 4, 100011.
Saka, A.B., Chan, D.W., 2021. Adoption and implementation of building information modelling (BIM) in small and medium-sized enterprises (SMEs): a review and conceptualization. ECAM 28 (7), 1829–1862.
Santos, E.T., 2009. BIM and ERP: finding similarities on two distinct concepts. In: Amorim, L de, Roberto, S. (Eds.), 5th Conference Information and Knowledge Management in Building. Deconstructing Babel.
Sarstedt, M., Mooi, E., 2019. A Concise Guide to Market Research. Springer Berlin Heidelberg, Berlin, Heidelberg, p. 407.
Scarponcini, P., 1996. Editorial: time for an integrated approach to facility management. JCCE 10 (1).
Seuring, S.A., 2003. Outsourcing into service factories. Int. J. Oper. Prod. Manag. 23 (10), 1207–1223.
Sheward, H., 2021. BIM based analysis of spatial properties in building layouts. Am. J. Civ. Eng. Architect. 9 (No. 4), 142–155.
Talamo, C., Atta, N., 2019. Invitations to Tender for Facility Management Services. Imprint: Springer, first ed. Springer International Publishing, Cham, Switzerland. 1 online resource (X, 261 pages 47 illustrations, 16 illustrations in color.
Teufelhart, N., 2013. Safety in laboratories. In: Dittrich, E. (Ed.), The Sustainable Laboratory Handbook. Wiley, Hoboken New Jersey, pp. 455–463.
Tian, B., Jiang, H., 2017. Developing building information modelling for facility services with organisational semiotics. In: Azcarate, A.L.-V. (Ed.), Interdisciplinary Approaches to Semiotics. InTech.
Tong, L., Pu, Z., Ma, J., 2019. Maintenance supplier evaluation and selection for safe and sustainable production in the chemical industry: a case study. Sustainability 11 (6), 1533.
Tsay, G.S., Staub-French, S., Poirier, É., 2022. BIM for facilities management: an investigation into the asset information delivery process and the associated challenges. Appl. Sci. 12 (19), 9542.
Uhm, M., Lee, G., 2021. Information requirements for managing higher education facilities using building information modeling: triangular study of US and Korean cases. JCCE 35 (6), 4021025.
Ullah, K., Witt, E., Lill, I., 2022. The BIM-based building permit process: factors affecting adoption. Buildings 12 (1), 45.
Wyman, O., 2018. Digitalization in the Construction Industry. https://www.oliverwyman.com/our-expertise/insights/2018/sep/digitalization-of-the-construction-industry.html;. (Accessed 2 August 2021).
Zeigler-Hill, V., Shackelford, T.K., 2017. Encyclopedia of Personality and Individual Differences. Springer International Publishing, p. 4.

References

Abideen, D. K., Yunusa-Kaltungo, A., Manu, P. and Cheung, C. (2022) 'A Systematic Review of the Extent to Which BIM Is Integrated into Operation and Maintenance', *Sustainability*, vol. 14, no. 14, p. 8692.

Alshorafa, R. and Ergen, E. (2020) 'Identification of information requirements for implementing Building Information Modeling based on model uses', *Journal of Information Technology in Construction*, vol. 25, pp. 561–574.

Ashworth, S., Druhmann, C. K. and Tucker, M. (2017) 'Employer's Information Requirements (EIR): A BIM case study to meet client and facility manager needs', *Research papers for EuroFM's 16th research symposium EFMC 2017.* Madrid, Spain, 25.04.2017 - 28.04.2017. Lyngby, Denmark, Polyteknisk Forlag.

Autodesk (ed) (2002) *Autodesk White Paper: Building Information Modeling* [Online], San Rafael, CA, USA. Available at https://journals.sagepub.com/doi/pdf/10.1177/003754976400200514?download=true (Accessed 19 June 2023).

Bauen digital Schweiz/ buildingSMART Switzerland (ed) (2019) *Bauen digital Schweiz/ BuildingSMART Switzerland: Kadertag Gebäudetechnik 2019* [Online]. Available at https://www.proklima.ch/CFDOCS/cms/admin/download.cfm?FileID=1237&GroupID=265&WatermarkMenuEntriesObjectID=436 (Accessed 3 May 2021).

Bauen digital Schweiz/ buildingSMART Switzerland (ed) (2020) *Datenfeldkatalog BIM2FM: Teil der Liegenschafts-Informationsanforderungen (LIA)* [Online], Zurich, Switzerland. Available at https://bauen-digital.ch/assets/Downloads/de/Leitfaden-BIM2FM-Datenfeldkatalog.pdf (Accessed 9 April 2021).

Bazjanac, V. and Crawley, D. B. (1997) *The Implementation of Industry Foundation Classes in Simulation Tools for the Building Industry* [Online], Lawrence Berkeley National Laboratory. Available at https://escholarship.org/uc/item/76c6z6g4 (Accessed 22 June 2032).

Becerik-Gerber, B., Jazizadeh, F., Li, N. and Calis, G. (2012) 'Application Areas and Data Requirements for BIM-Enabled Facilities Management', *Journal of Construction Engineering and Management*, vol. 138, no. 3, pp. 431–442.

BIMe initiative (ed) (2023) *Model Use Templates* [Online]. Available at https://bimexcellence.org/projects/integrated-information-project/model-use-templates/ (Accessed 7 February 2023).

Blackburn, R., Lurz, K., Priese, B., Göb, R. and Darkow, I.-L. (2015) 'A predictive analytics approach for demand forecasting in the process industry', *International Transactions in Operational Research*, vol. 22, no. 3, pp. 407–428.

Braun, B., Dessauer, M., Henderson, K., Peng, Y. and Seasholtz, M. B. (2022) 'Methodology to screen vendors for predictive maintenance in the chemical industry', *Journal of Advanced Manufacturing and Processing*, vol. 4, no. 1.

buildingSMART Alliance (ed) (2013) *National BIM Standard - United States® Version 3 - 5.7 BIM Planning Guide for Facility Owners, Version 2.0 – June 2013* [Online]. Available at https://www.nationalbimstandard.org/nbims-us (Accessed 30 April 2021).

buildingSMART International (ed) (2023) *Use Case Management* [Online]. Available at https://ucm.buildingsmart.org/ (Accessed 7 February 2023).

buildingSMART Technical (2023) *IFC Formats - buildingSMART Technical* [Online]. Available at https://technical.buildingsmart.org/standards/ifc/ifc-formats/ (Accessed 27 June 2023).

Carbonari, G., Stravoravdis, S. and Gausden, C. (2018) 'Improving FM task efficiency through BIM: a proposal for BIM implementation', *Journal of Corporate Real Estate*, vol. 20, no. 1, pp. 4–15.

Cardoso Ermel, A. P., Lacerda, D. P., Morandi, M. I. W. M. and Gauss, L. (2021) *Literature Reviews: Modern Methods for Investigating Scientific and Technological Knowledge*, Cham, Springer.

Cavka, H. B., Staub-French, S. and Poirier, E. A. (2017) 'Developing owner information requirements for BIM-enabled project delivery and asset management', *Automation in Construction*, vol. 83, pp. 169–183.

Chen, Y.-R. and Tserng, H. P. (2017) 'An Integrated Methodology for Construction BIM & ERP by using UML Tool', *Proceedings of the 34th International Symposium on Automation and Robotics in Construction (ISARC)*. Taipei, Taiwan, 28.06.2017 - 01.07.2017, Tribun EU, s.r.o., Brno.

Chin, H. H., Varbanova, P. S., Klemes, J. J., Benjamin, M. F. D. and Tan, R. R. (2020) 'Asset maintenance optimisation approaches in the chemical and process industries - A review', *Chemical engineering research & design: transactions of the Institution of Chemical Engineers*, vol. 164, pp. 162–194.

Comité Européen de Normalisation (2011) *15221-4:2011: Facility Management - Part 4: Taxonomy, Classification and Structures in Facility Management*, Brussels, Belgium.

Dekkers, R., Carey, L. D. and Langhorne, P. (2022) *Making Literature Reviews Work: A Multidisciplinary Guide to Systematic Approaches*, Cham, Springer.

Deutsches Institut für Normung e.V. (DIN) (ed) (2021) *Deutsche Normungsroadmap BIM: Version 1* [Online], Berlin, Germany. Available at https://www.din.de/de/din-und-seine-partner/presse/mitteilungen/breite-anwendung-von-bim-foerdern-847244 (Accessed 16 December 2021).

Dixit, M. K., Venkatraj, V., Ostadalimakhmalbaf, M., Pariafsai, F. and Lavy, S. (2019) 'Integration of facility management and building information modeling (BIM): A review of key issues and challenges', *Facilities*, vol. 37, 7/8, pp. 455–483.

Eastman, C., Fisher, D., Lafue, G., Lividini, J., Stoker, D. and Yessios, C. (1974) 'An Outline of the Building Description System' [Online]. Available at http://files.eric.ed.gov/fulltext/ED113833.pdf.

Eastman, C. and Henrion, M. (1977) 'GLIDE a language for design information systems', *Proceedings of the 4th annual conference on Computer graphics and interactive techniques - SIGGRAPH '77.* San Jose, California, 20.07.1977 - 22.07.1977. New York, New York, USA, ACM Press, pp. 24–33.

Edirisinghe, R., London, K. A., Kalutara, P. and Aranda-Mena, G. (2017) 'Building information modelling for facility management: are we there yet?', *Engineering, Construction and Architectural Management*, vol. 24, no. 6, pp. 1119–1154.

EU BIM Task Group (ed) (2018) *Handbook for the introduction of Building Information Modelling by the European Public Sector: Strategic action for construction sector performance: driving value, innovation and growth* [Online]. Available at http://www.eubim.eu/handbook-selection/ (Accessed 2 August 2021).

European Commission (2008) *NACE Rev. 2: Statistical classification of economic activities in the European Community* [Online], Luxembourg, Luxembourg, Office for Official Publications of the European Communities. Available at ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF.

European Construction Sector Observatory (ECSO) (ed) (2021) *Digitalisation in the construction sector: Analytical Report* [Online]. Available at https://ec.europa.eu/docsroom/documents/45547 (Accessed 2 August 2021).

Flick, U. (2018) *The SAGE Handbook of Qualitative Data Collection* [Online], 1 Oliver's Yard, 55 City Road London EC1Y 1SP. Available at https://sk.sagepub.com/reference/the-sage-handbook-of-qualitative-data-collection/i3530.xml?term=Triangulation (Accessed 24 January 2023).

Franke, F., Kempe, H., Klein, A., Rumpf, L. and Schüller-Zwierlein, A. (2014) *Schlüsselkompetenzen: Literatur recherchieren in Bibliotheken und Internet*, Stuttgart, Germany, J.B. Metzler.

Gerbert, P., Castagnino, S., Rothballer, h., Re, A. and Filitz, R. (2016) *The Transformative Power of Building Information Modeling: Digital in Engineering and Construction* [Online]. Available at https://www.bcg.com/de-de/publications/2016/engineered-products-infrastructure-digital-transformative-power-building-information-modeling (Accessed 2 August 2021).

German Facility Management Association e.V. (2004) *100-2:2004-07: Facility management*, Berlin, Germany: German Facility Management Association.

Glatte, T. (2021) *Corporate Real Estate Management*, Wiesbaden, Germany, Springer Fachmedien Wiesbaden.

Hewavitharana, F. S. T. and Perera, A. A. D. A. J. (2020) 'Sustainability via ERP and BIM Integration', *Icsbe 2018: Proceedings of the 9th International Conference on Sustainable Built Environment.* Singapore, Springer Singapore Pte. Limited, pp. 202–210.

Heywood, C. and Kenley, R. (2013) 'Five axioms for corporate real estate management: A polemical review of the literature', *Proceedings from the PRRES Conference - 2013*. Melbourne, Australia, 13.01.2013 - 16.01.2013.

Homburg, C., Klarmann, M. and Vomberg, A. (eds) (2022) *Handbook of market research*, Cham, Switzerland, Springer.

International Organisation for Standardisation (2016) *29481-1:2016: Building information models - Information delivery manual*, Geneva, Switzerland: International Organisation for Standardisation (ISO).

International Organisation for Standardisation (2017a) *15686-5:2017: Buildings and constructed assets - Service life planning*, Geneva, Switzerland: International Organisation for Standardisation (ISO).

International Organisation for Standardisation (2017b) *41011:2017: Facility management*, Geneva, Switzerland: International Organisation for Standardisation (ISO).

International Organisation for Standardisation (2018a) *19650-1:2018: Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 1: Concepts and principles*, Geneva, Switzerland: International Organisation for Standardisation (ISO).

International Organisation for Standardisation (2018b) *19650-2:2018: Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 2: Delivery phase of the assets*, Geneva, Switzerland: International Organisation for Standardisation (ISO).

International Organisation for Standardisation (2020) *19650-3:2020: Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 3: Operational phase of the assets*, Geneva, Switzerland: International Organisation for Standardisation (ISO).

Joseph, J. (2011) *BIM Titles and Job Descriptions: How Do They Fit in Your Organizational Structure?* [Online]. Available at https://onlinebimeducation.com/2017/05/18/bim-roles-and-responsibilities/ (Accessed 14 June 2021).

Krumm, P. J. (2001) 'History of real estate management from a corporate perspective', *Facilities*, vol. 19, 7/8, pp. 276–286.

Landis, J. R. and Koch, G. G. (1977) 'The Measurement of Observer Agreement for Categorical Data', *Biometrics*, vol. 33, pp. 159–174.

Lazar, S. and McArthur, J. J. (2016) 'BIM for Corporate Real Estate Data Visualization from Disparate Systems', in Leon-Garcia, A., Lenort, R., Holman, D., Staš, D., Krutilova, V., Wicher, P., Cagáňová, D., Špirková, D., Golej, J. and Nguyen, K. (eds) *Smart City 360°,* Cham, Switzerland, Springer International Publishing, pp. 504–516.

Lewis, A., Riley, D. and Elmualim, A. (2010) 'Defining High Performance Buildings for Operations and Maintenance', *International Journal of Facility Management*, vol. 1, no. 2.

Little, A. D., Samoylova, M., Wilmet, S., Witthaut, D. and Kolk, M. (2023) *Digital technologies for sustainability in the European chemical industry* [Online], European Chemical Industry Council. Available at https://cefic.org/library-item/digital-technologies-for-sustainability-in-the-european-chemical-industry (Accessed 28 July 2023).

Loosen, W. (2015) 'Das Leitfadeninterview – eine unterschatzte Methode', in Averbeck-Lietz, S. and Meyen, M. (eds) *Handbuch nicht standardisierte Methoden in der Kommunikationswissenschaft* [Online], Wiesbaden, Springer Fachmedien Wiesbaden, pp. 139–155. Available at http://nbn-resolving.org/urn:nbn:de:bsz:31-epflicht-1587749.

Matarneh, S. T., Danso-Amoako, M., Al-Bizri, S., Gaterell, M. and Matarneh, R. (2019a) 'BIM-based facilities information: streamlining the information exchange process', *Journal of Engineering, Design and Technology*, vol. 17, no. 6, pp. 1304–1322.

Matarneh, S. T., Danso-Amoako, M., Al-Bizri, S., Gaterell, M. and Matarneh, R. (2019b) 'Building information modeling for facilities management: A literature review and future research directions', *Journal of Building Engineering*, vol. 24 [Online]. DOI: 10.1016/j.jobe.2019.100755 (Accessed 23 February 2021).

Mayo, G. and Issa, R. R. A. (2016) 'Nongeometric Building Information Needs Assessment for Facilities Management', *Journal of Management in Engineering*, vol. 32, no. 3, p. 4015054.

McArthur, J. J. and Sun, X. (2015) 'Best practices for BIM Execution Plan development for a Public–Private Partnership Design-Build-Finance-Operate-Maintain project', *Building Information Modelling (BIM) in Design, Construction and Operations,* WIT PressSouthampton, UK, pp. 119–130.

Messner, J., Anumba, C., Dubler, C., Goodman, S., Kasprzak, C., Kreider, R., Leicht, R., Saluja, C. and Zikic, N. (2019) *BIM Project Execution Planning Guide - Version 2.2* [Online], University Park, PA, USA, The Pennsylvania State University. Available at https://bim.psu.edu/ (Accessed 3 February 2021).

Munir, M., Kiviniemi, A., Jones, S. and Finnegan, S. (2020) 'BIM-based operational information requirements for asset owners', *Architectural Engineering and Design Management*, vol. 16, no. 2, pp. 100–114.

Munir, M., Kiviniemi, A. and Jones, S. W. (2019) 'Business value of integrated BIM-based asset management', *Engineering, Construction and Architectural Management*, vol. 26, no. 6, pp. 1171–1191.

Nase, I. and Arkesteijn, M. (2018) 'Corporate real estate strategies and organizational culture', *Journal of Corporate Real Estate*, vol. 20, no. 3, pp. 154–176.

Nojedehi, P., O'Brien, W. and Gunay, H. B. (2022) 'A methodology to integrate maintenance management systems and BIM to improve building management', *Science and Technology for the Built Environment*, pp. 1–18.

Omar, A. J. and Heywood, C. A. (2014) 'Defining a corporate real estate management's (CREM) brand', *Journal of Corporate Real Estate*, vol. 16, no. 1, pp. 60–76.

Pärn, E. A., Edwards, D. J. and Sing, M. (2017) 'The building information modelling trajectory in facilities management: A review', *Automation in Construction*, vol. 75, pp. 45–55.

Pasini, D., Caffi, V., Daniotti, B., Lupica Spagnolo, S. and Pavan, A. (2017) 'The INNOVance BIM library approach', *Innovative Infrastructure Solutions*, vol. 2, no. 1.

Pavan, A., Lupica Spagnolo, S., Caffi, V., Mirarchi, C. and Daniotti, B. (2020) 'National BIM Digital Platform for Construction (INNOVance Project)', in Daniotti, B., Gianinetto, M. and Della Torre, S. (eds) *Digital Transformation of the Design, Construction and Management Processes of the Built Environment,* Cham, Springer International Publishing, pp. 3–15.

Pearson, K. (1905) *XIV. On the General Theory of Skew Correlation and Non-linear Regression: Mathematical contributions to the theory of evolution*, Cambridge, UK, University of Cambridge.

Pfnür, A. (2014) *Volkswirtschaftliche Bedeutung von Corporate Real Estate in Deutschland* [Online], Darmstadt, Germany. Available at https://www.aurelis-real-estate.de/fileadmin/user_upload/Bilder/News/Studien/Studie_CREM.pdf (Accessed 15 February 2021).

Port, S. (1989) *The management of CAD for construction*, New York, Van Nostrand Reinhold.

Sacks, R., Girolami, M. and Brilakis, I. (2020) 'Building Information Modelling, Artificial Intelligence and Construction Tech', *Developments in the Built Environment*, vol. 4, p. 100011.

Santos, E. T. (2009) 'BIM and ERP: Finding Similarities on Two Distinct Concepts', *5th Conference Information And Knowledge Management In Building: Deconstructing Babel.* Rio de Janeiro, Brazil, 17.06.2009 - 19.06.2009.

Sarstedt, M. and Mooi, E. (2019) *A Concise Guide to Market Research*, Berlin, Heidelberg, Springer Berlin Heidelberg.

Scarponcini, P. (1996) 'Editorial: Time for an Integrated Approach to Facility Management', *Journal of Computing in Civil Engineering*, vol. 10, no. 1.

Scott Jones, J. (2019) *Learn to Use the Eta Coefficient Test in R With Data From the NIOSH Quality of Worklife Survey (2014)* [Online], 1 Oliver's Yard, 55 City Road, London EC1Y 1SP United Kingdom. Available at https://methods.sagepub.com/dataset/eta-coefficient-niosh-qwl-2014?fromsearch=true (Accessed 20 December 2021).

See, R. (2007) 'Building Information Models and Model Views', *Journal of Building Information Modeling (JBIM)*, Fall, pp. 20–25.

Sheward, H. (2021) 'BIM Based Analysis of Spatial Properties in Building Layouts', *American Journal of Civil Engineering and Architecture*, Vol. 9, No. 4, pp. 142–155 [Online]. Available at http://pubs.sciepub.com/ajcea/9/4/3 (Accessed 17 April 2023).

Sobhkhiz, S., Zhou, Y.-C., Lin, J.-R. and El-Diraby, T. E. (2021) 'Framing and Evaluating the Best Practices of IFC-Based Automated Rule Checking: A Case Study', *Buildings*, vol. 11, no. 10, p. 456.

Stockemer, D. (2019) *Quantitative Methods for the Social Sciences*, Cham, Switzerland, Springer International Publishing.

Taber, K. S. (2018) 'The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education', *Research in Science Education*, vol. 48, no. 6, pp. 1273–1296.

Tong, L., Pu, Z. and Ma, J. (2019) 'Maintenance Supplier Evaluation and Selection for Safe and Sustainable Production in the Chemical Industry: A Case Study', *Sustainability*, vol. 11, no. 6, p. 1533.

van der Voordt, T. (2017) 'Facilities management and corporate real estate management: FM/CREM or FREM?', *Journal of Facilities Management*, vol. 15, no. 3, pp. 244–261.

van Nederveen, G. A. and Tolman, F. P. (1992) 'Modelling multiple views on buildings', *Automation in Construction*, vol. 1, no. 3, pp. 215–224.

Wagner-Schelewsky, P. and Hering, L. (2019) 'Online-Befragung', in Baur, N. and Blasius, J. (eds) *Handbuch Methoden der empirischen Sozialforschung,* Wiesbaden, Springer Fachmedien Wiesbaden, pp. 787–800.

Wilkinson, S. J. and Jupp, J. R. (2016) 'Exploring the value of BIM for corporate real estate', *Journal of Corporate Real Estate*, vol. 18, no. 4, pp. 254–269.

Wu, B., Liang, H., Shi, Y. and Zhu, J. (2020) 'Research on the Construction of Construction Engineering Cost construction Information System Based on BIM Technology', *Journal of Physics: Conference Series*, vol. 1650, no. 3, p. 32064.

Yin, R. K. (2016) *Qualitative research from start to finish*, New York, London, The Guilford Press.