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Conceptual Framework of Construction Data Storage using Gaia-X Federation Services: Demonstration with Usecase of Project iECO

Master Thesis

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Author: Pintukumar Nakrani

Matriculation No.: [redacted]

Supervisors: Prof. Dr.-Ing. André Borrmann

M.Sc. Jonas Urs Schlenger

Dipl.-Ing. Wolfgang Müller (RIB Software AG & 5D Institut)

Dr. Christof Duvenbeck (RIB IMS GmbH)

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Preface

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Abstract

Digitalizing construction processes generates huge amount of data, which has great potential for society and the economy. If data is used for the optimization of the construction processes, it might contribute to sustainability. As a building's construction phase progresses, it generates different kinds of data for different processes. The owner stores this data and might share it with facility management (FM) service providers. The FM service provider might use this data for building operation and maintenance (O&M). Paper-based facility data transmission is slow and error-prone, and digital data transfer and storage are vulnerable to malpractice nowadays.

Gaia-X ecosystem has been an emerging European data ecosystem since 2019. Gaia-X members can use Gaia-X Federation Services (GXFS) functionalities to leverage sovereign data infrastructure benefits. The Gaia-X data ecosystem is being developed for many industrial and commercial initiatives. On the basis of Smart Advanced Services (SAS), the project iECO enables the use of a digital twin throughout the construction life cycle, creating new value for the construction industry. Project iECO's six usecase digitally depict the building construction life cycle. The project iECO's usecases demonstrate Gaia-X's enormous potential for the building sector. These include data flow across corporate boundaries and data delivery to stakeholders.

The thesis integrates Project iECO with GXFS. GXFS could make usecase implementation easier across the Gaia-X ecosystem. The historical, current, and future trends for construction data collection, storage, and utilization methods are studied to assess the state of the art for data in the construction industry. For non-Gaia-X users, the Gaia-X ecosystem has been simplified and explained. Project iECO usecases have been conceptualized and demonstrated with GXFS. The iECO dataspace is realized to demonstrate how other Gaia-X dataspaces would benefit from iECO data, and a consumer-oriented decentralized Gaia-X strategy with an example is explored.

Keywords: Gaia-X, Data Ecosystem, iECO, Data Management System (DMS), AI-led Operation, Gaia-X Federation Services (GXFS), Smart Advanced Services (SAS), Construction Digital Twin

Zusammenfassung

Die Digitalisierung von Bauprozessen erzeugt enorme Datenmengen, die ein großes Potenzial für Industrie und Wirtschaft darstellen. Wenn die Daten zur Optimierung der Bauprozesse genutzt werden, können sie zur Nachhaltigkeit beitragen. Während der Bauphase eines Gebäudes fallen verschiedene Daten für unterschiedliche Prozesse an. Der Eigentümer speichert diese Daten und gibt sie möglicherweise an Facility Management (FM)-Dienstleister weiter. Der FM-Dienstleister kann diese Daten für den Betrieb und die Wartung des Gebäudes nutzen. Die papiergestützte Übertragung von Gebäudedaten ist langsam und fehleranfällig, und die digitale Datenübertragung und -speicherung ist heutzutage anfällig für Missbrauchsfälle.

Das Gaia-X-Ökosystem ist seit 2019 ein europäisches Daten-Ökosystem im Wachstum. Gaia-X-Mitglieder können die Funktionalitäten der Gaia-X Federation Services (GXFS) nutzen, um die Vorteile einer souveränen Dateninfrastruktur auszuschöpfen. Das Gaia-X-Datenökosystem wird für zahlreiche industrielle und kommerzielle Initiativen entwickelt. Auf der Grundlage von Smart Advanced Services (SAS) ermöglicht das Projekt iECO die Nutzung eines digitalen Zwillings während des gesamten Lebenszyklus eines Bauwerks und schafft damit neue Mehrwerte für die Bauindustrie. Die sechs Usecases des Projekt iECO ermöglichen die digitale Darstellung des Lebenszyklus von Gebäuden. Die Usecases des Project iECO zeigen das enorme Potenzial von Gaia-X für den Bausektor. Dazu gehören der Datenfluss über Unternehmensgrenzen hinweg und die Bereitstellung von Daten für die Beteiligten.

Die Arbeit integriert das Projekt iECO mit GXFS. GXFS könnte die Implementierung von Anwendungsfällen im gesamten Gaia-X-Ökosystem erleichtern. Die historischen, aktuellen und zukünftigen Trends für die Erfassung, Speicherung und Verarbeitung von Baudaten werden untersucht, um den Stand der Technik für Daten in der Bauindustrie zu bewerten. Für Nicht-Gaia-X-Nutzer wurde das Gaia-X-Ökosystem vereinfacht und erklärt. Die Anwendungsfälle des iECO-Projekts wurden konzeptioniert und mit GXFS demonstriert. Der iECO-Datenraum wird realisiert, um zu demonstrieren, wie andere Gaia-X-Datenräume von iECO-Daten profitieren können, und es wird eine verbraucherorientierte dezentrale Gaia-X Strategie anhand eines Beispiels vorgestellt.

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List of Abbreviations

AEC	Architecture, Engineering and Construction Industry
AG	Aktiengesellschaft
AI / KI	Artificial Intelligence / Künstliche Intelligence
AISBL	Association internationale sans but lucratif (Belgium)
API	Application Protocol Interface
AWS	Amazon Wireless Services
BCF	BIM Collaboration Format
DMS	Data Management System
BIM	Building Information Model
BPMN	Business Process Model and Notation
CAD	Computer Aided Design
CDE	Common Data Environment
DLT	Distributed Ledger Technology
DMS	Database Management System
EU	European Union
FM	Facility Management / Facility Manager (Role)
FS	Federation Services
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GIS	Geographical Information System
GmbH	Gesellschaft mit beschränkter Haftung
GPS	Global Positioning System
GXFS	Gaia-X Federation Services

HVAC	Heating, Ventilation and Air-Conditioning System
iECO	Intelligent Empowerment of Construction Industry
IFC	Industry Foundation Classes
IoT	Internet of Things
IT	Information Technology
JSON-LD	JavaScript Object Notation for Linked Data
LCM	Life Cycle Management
MEP	Mechanical, Electrical, Plumbing
PDF	Portable Document Format
R&M	Repairing and Maintenance
RDF	Resource Description Framework
RFID	Radio Frequency Identification
SAS	Smart Advanced Services / Advanced Smart Services
SD	Self-Description
SME	Small and Medium Enterprises
SRS	Software Requirement Specifications
SSI	Self-Sovereign Identity
UC	Usecase / Use Case
UI	User Interface
W3C	World Wide Web Consortium

1 Introduction

1.1 Current Situation

As of 2021, the construction industry employed approximately 26 million people in the European Union (EU), accounting for 10% of all employment in the EU. In the EU, the share in the gross domestic product (GDP) for the building industry is almost 8%. The EU economy greatly depends on the construction sector. The construction sector supports economic expansion, generates new employment, and offers fresh approaches to energy, social, and environmental problems in EU (EU-SME Web, 2021). In context of German construction industry, around 2.2 million people were working in the construction sector as of 2021, and GPD share of around 6% (DESTATIS, 2022). The construction sector is distinguished by a high level of specialization, with companies typically specializing in certain areas like residential, commercial, or infrastructure construction. Due to factors such as population growth, urbanisation, and infrastructure investment, the German construction industry is expected to thrive over the next decades and continues to play a significant role in the German economy.

The construction industry is facing several data-related issues, such as siloed data, a lack of interoperability and collaboration, malpractices, etc. In construction projects, the generated data is generally managed by the contractor and stored in a private project-specific database, making it challenging to integrate and provide access to the databases to the other involved stakeholders. The lack of data collection and storage standards in the construction industry makes it difficult to manage data across projects and frequently leads to data loss, misuse of proprietary information, fraud, and unauthorized changes in design.

The COVID-19 pandemic accelerated the use of digital technologies by the construction industry's many disciplines. Building Information Modelling (BIM) systems with intelligence, data analytics software, and other tools have all been embraced by the construction industry. Business executives may gather and evaluate a sizable quantity of data using each of these technologies (Massey, 2021). This kind of advancement and use of digital tools in the construction sector generates a huge amount of data that should be handled properly and has the potential to create value for a country’s economy.

Due to its complexity and cross-disciplinary nature, the construction sector requires effective collaboration between several stakeholders. Failure of these stakeholders to collaborate on the project can result in a variety of issues that can jeopardize the project's timely completion and increase the risk of cost overruns (Pauna et al., 2021). The procedure for obtaining a building permit, which sometimes includes several departments and agencies, is a typical example of this. Lack of cooperation between these parties can cause the process to stall out in bureaucracy and delays, troubling both building owners and contractors (Fauth, 2021). Along with delays, a lack of coordination can lead to cost overruns, inadequate quality, and conflicts between stakeholders. In the construction industry, efficient coordination is crucial to ensuring that projects are finished on schedule, within budget, and to the highest possible quality standards. To assure project success and reduce the risks of delays, cost overruns, and inferior quality, the construction industry needs extensive coordination and communication amongst all participants (Turk, 2020).

1.2 Motivation

Large volumes of data in the construction industry are kept idle, which has the potential to generate economic value. The potential for integrating data from several sectors is undiscovered. Main issue is a lack of confidence in the way that data is stored, shared, and handled. Customers of cloud services still worry that they could lose control of their private data or be stuck with a single service provider after putting it in the cloud, as changing from one cloud provider to another is sometimes restricted or there is a chance of data loss. Due to the complexity of the required technological methods for data exchange, implementation efforts and financial expenditures are at risk in the absence of a broadly accepted set of standard guidelines. Gaia-X ecosystem gets rid of these problems by making a framework where everyone agrees on a single set of rules that aim for a shared set of values. The goal is to build confidence among all the required players, technology providers, and consumers (Orfanou, 2021).

Trusted cloud-based services and shared data spaces are the foundations of the digital economy. Gaia-X intends to define and provide a transparent and reliable framework to significantly speed up the migration of European data to the cloud, allowing the establishment of European Data Spaces, essential for a new digital economy (Bonfiglio, 2021). The basic principles that Gaia-X promotes through its framework, which was created through a community-driven approach, include data sovereignty, privacy and confidentiality, security, technological autonomy, and interoperability (Weiss, 2022).. In 2019, Germany and France started the Gaia-X project with sovereign data sharing and compliance requirements to enable Europe to function independently of these entities. Currently, many EU countries have joined the initiative and are developing further usecases.

The construction sector has less access to information because of the ambiguity around standards and the unavailability of interoperable knowledge platforms. Digital standard protocols include inherent flaws that make it possible for human error, sabotage, and the manipulation of specific data. Such protocols were created for a trusting and open community. The development of data storage systems has been hampered by a lack of suitable archiving technologies. It implies that there has to be a strategy for developing new digital standards, protocols, and information platforms for global usage (Gyampoh-Vidogah & Moreton, 2005).

Project iECO (intelligent Empowerment of Construction Industry) is intended to overcome the issues related to the inefficiency and lack of digitalized processes in the construction sector by realizing a digital twin of the entire lifespan of the building using SAS. The usecases developed for project iECO are intended to demonstrate the huge potential that Gaia-X offers the construction industry. This specifically involves the reliable and scalable transfer of data across organizational boundaries and the distribution of data to diverse stakeholders (Mittelstand 4.0, 2022).

1.3 Objective

The goal of this thesis is to use flowchart representation to demonstrate integration of the Project iECO usecase with Gaia-X federation services (GXFS). The thesis is concerned with the construction data generated during the construction process by the project iECO usecases. Gaia-X adds value to the data storage and use process with features like GXFS, which create a trusted environment for data exchange and interoperability with other Gaia-X dataspaces. With conceptual and operational models, an all-in-one and simplified context for the Gaia-X data ecosystem architecture is discussed so that non-Gaia-X users can get the idea of Gaia-X. The GXFS are a crucial component of Gaia-X for establishing a federation of infrastructure and data and promoting interoperability across federations. The project's context and objective are also discussed to get an overview of the processes and services it could offers to the construction industry.

Over the course of this thesis, in the context of the construction industry, the data is referred to as "building data" or "construction data".

1.4 Methodology

The approach begins with a theoretical discussion to gain a broad perspective on construction data, with analysis ranging from the past to the future in terms of methodologies and strategies for data collection, storage, and utilization of building data. A simplified overview of the Gaia-X ecosystem, with its technical architecture and operational architecture, is discussed in detail. The Gaia-X ecosystem has a wide range of components, making it challenging for non-Gaia-X users to comprehend. The concept could be easier to understand if you use the simplified explanation of Gaia-X that has been presented. The background of project iECO is discussed in the next step, as are its SASs and dataspace. Usecases are briefly covered since each of its six usecases is crucial to the realization of the digital twin of the building's life cycle. One usecase is picked as the demonstration usecase for the integration with GXFS. The usecase is described in detail, along with its sub-processes and flowcharts. The demonstration will be carried out via the federation services' (FS) visual integration into the usecase flowchart. To follow the usecase procedures, the FS integration processes are briefly described. The results are discussed as part of the project iECO usecase framework, and the decentralized, consumer-focused-Gaia-X approach is illustrated with an example of a consumer of the data in the Gaia-X ecosystem. The Gaia-X ecosystem's possible technical, economical, and organizational challenges are highlighted.

Figure 1.1 outlines the structure of the thesis.

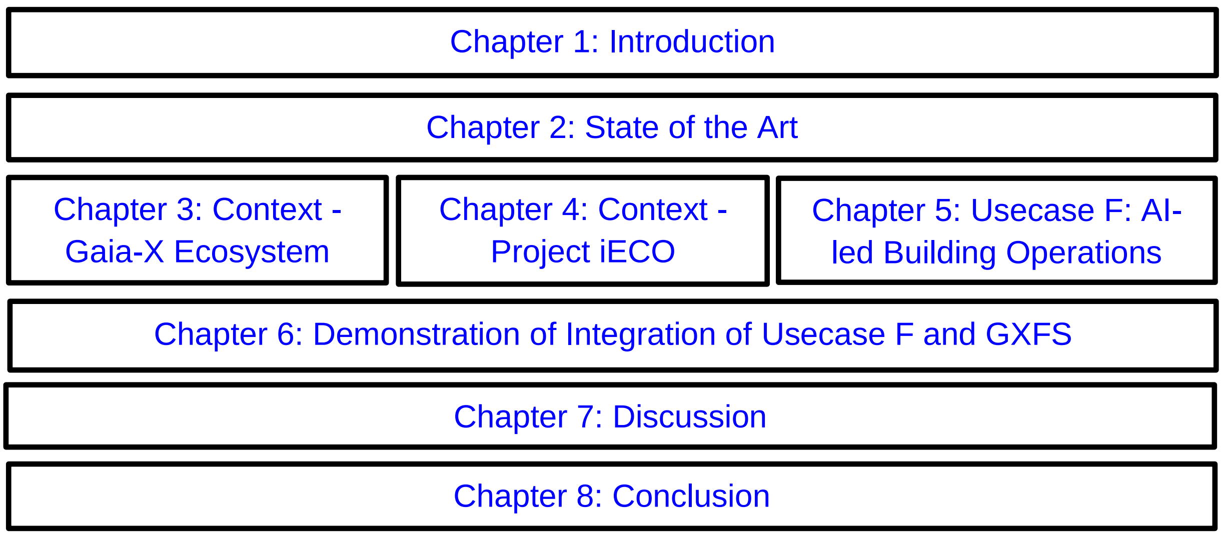

Figure 1.1: Structure of the thesis

2 State of the Art

The construction sector has adopted new technology much more slowly than many other industries, and it is only now starting to undergo a technological transition. Although construction companies have been sluggish to adopt new approaches, they are increasingly beginning to give a building's whole life cycle greater consideration. Technology increases the value at every stage of construction, from planning to commissioning, by increasing productivity and efficiency (Gopal, 2019). The efficiency of the construction sector is being pushed, and new technologies are being adopted to enhance communication and collaboration in construction procedures. To increase efficiency, data collection and analysis are essential, and technologies like BIM are key to gathering, linking, and enhancing collaboration and data communication. It is anticipated that the construction industry could change course thanks to cutting-edge technologies, innovative building techniques, and an emphasis on sustainability (Clavero, 2022).

Architectural and engineering plans, which include comprehensive details on the building's layout, systems, and components, are produced during the design and planning stage. This data is utilized to make sure the building complies with the relevant building regulations. Data from the various processes is gathered during construction through site inspections, material measurements, documentation of procedures and activities, etc. Informed choices regarding the project's budget and schedule are made using this data to track its progress (Landau, 2022). After the construction work is finished, data is produced and used by facility management (FM) for the continuous monitoring and maintenance of the heating, ventilation, and air conditioning (HVAC) systems of the building. This data is used to improve building performance, identify and resolve problems, and ensure the building's durability (Sapp, 2017).

Building data is significant because it can provide us important information about how buildings are built and maintained. It aids in decision-making, enhances building performance, ensures safety and regulatory compliance, and lessens the environmental effect of buildings. Building data may also be utilised to create new technologies and construction techniques that could make buildings safer, more sustainable, and more effective (Omar, 2018). The current trend indicates that there is potential for value to be created by using collected construction data. The stored data may be used to improve building designs and operations in future. The emerging data ecosystems such as Gaia-X data ecosystem facilitates the generating value from the construction data in secure and sovereign way (Ladid et al., 2021).

This chapter examines the historical, current, and anticipated future trends for the collection, storage, and utilization of building data. On a construction site, data sharing and interoperability standards are examined. The datasets for the data produced during the lifecycle of a building are reviewed. Several data management systems (DMSs) in the context of buildings are discussed. Data storage for building site data is explored. The new technologies on the construction site that can aid the functioning of construction processes are explored.

2.1 Historical Trend - Construction Data

Historically, for construction and building-related data collection, paper-based forms and blueprints were used. Among the popular techniques are paper forms filled out by hand that are used to record information such as the amount of materials used, the number of hours worked by a worker, the equipment used, etc. As construction plans were frequently hand-drawn and maintained on paper, it was challenging to communicate with stakeholders and work together. Physical examination was frequently used to evaluate the quality of building work and record any flaws or problems (Claypool, 2019). Instruments of surveying for on-site data collection included measurements of building elevations and separations between locations using surveying tools, including total stations and theodolites. Using tape measures and rulers, measurements were manually taken on the spot, such as the size of rooms or the length of steel beams (Busen et al., 2022).

For the storage of the collected construction data, blueprint storage, file cabinets, and paper-based designs were all tangible techniques used to store building data. Typical techniques included paper construction plans. It was challenging to store, organize, and retrieve information since construction plans were frequently hand-drawn and preserved on paper. Physical copies of the data and plans were kept in file cabinets, making it challenging to access the data and monitor changes. Large-format building plans, sometimes referred to as "blueprints," were kept in blueprint storage systems, which were frequently challenging to access and administer. Measurement and quality reports and other data were frequently kept in hard copy format, which made it challenging to communicate information and work with other stakeholders.

The manual and physical ways of collection and storing data have restrictions on access, organisation, and modification tracking. These manual techniques were often prone to the mistakes. With the development of technology, data collection and storage for the construction industry has become more effective and efficient, making the processes of the construction site easily accessible and collaborative. Enabling better project results, more informed decision-making and timely completion of the construction work (Akhavian & Behzadan, 2012).

2.2 Current Trend - Construction Data

Nowadays data collection methods used on typical construction sites include both manual and digital technologies. The approaches mostly depend on the scale of the construction project. Smaller construction sites mostly employ manual data collecting techniques since they are practical and economical, but larger sites use digital techniques like BIM, artificial intelligence (AI), internet of things (IoT), virtual reality (VR), drones, closed circuit television (CCTV) cameras, etc. The process of gathering real-time data and enhancing site efficiency via IoT devices, such as sensors and smart equipment (Agarwal et al., 2016).

Digital techniques and cloud-based solutions are currently the preferred options for storing construction data. Cloud-based data storage method is gaining popularity since it makes it simple to retrieve data from any location with an internet connection. Users can save data and files using cloud storage in an off-site location that is connected to a dedicated private network or the public internet (IBM, 2022). Digital document management systems that store, organise, and provide stakeholders with access to construction data. These systems improve communication and information access through their easy management interfaces (Ribeiro et al., 2010).

BIM is being utilised more often to develop digital representations of building projects, including data storage and project team collaboration. The collaboration and real-time data access makes the cloud-based method more usable (Abbasnejad et al., 2021). Automated data backup guarantees that data is safe and simple to retrieve in the case of a disaster, automated data backup solutions are being deployed. Secure data storage is being utilised to safeguard private and sensitive construction data, including financial and personal data (CLOUDIAN, 2022).

In today's construction data context, it is vital to comprehend data interchange on construction sites, data sets that are commonly utilized throughout the life-cycle of a building, the data management system that leads the current usage scenarios in real-world situations, and how the information is maintained. These are some of the aspects that comprise one ecosystem of construction data and its administration.

2.2.1 Data Exchange and Interoperability

Interoperability between various software tools and processes, as well as data exchange between various construction site stakeholders, are key components for efficient execution. A lack of interoperability results in the elimination of the manual data input, duplication of administrative tasks and reliance on paper for data duplication and interchange. Benefits of interoperability includes overall faster project delivery, less vulnerable infrastructure, more reliable information throughout a project's lifespan, cheaper supply-chain communication and better value for customers (Aranda et al., 2015).

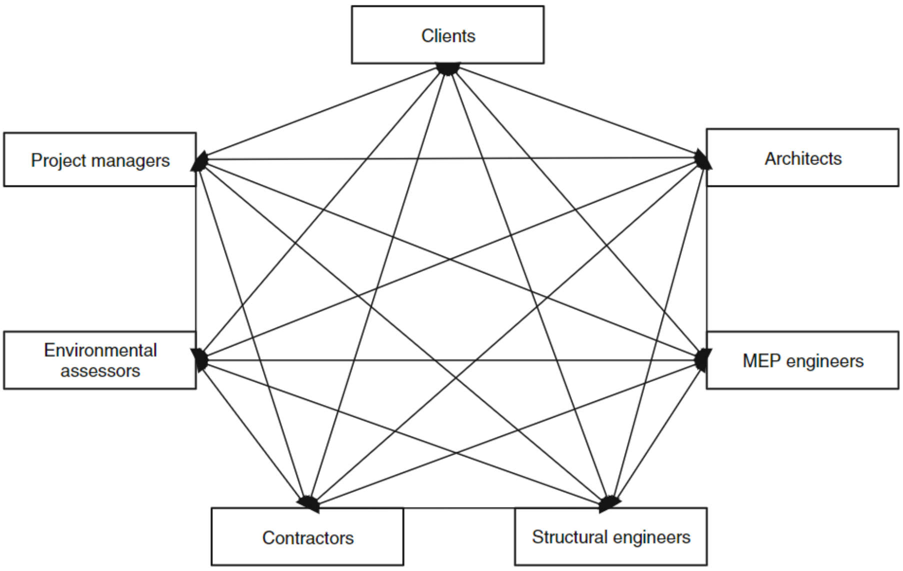

Figure 2.1: Data exchange in conventional project (Alreshidi et al., 2018)

Data exchange amongst interdisciplinary participants in a typical construction project is shown in Figure 2.1. The degree of contact rises with geographically dispersed team members and relates to project complexity. Typical file-based methods frequently cause data integrity to be lost and error rates to rise. Since data transmission occurs in both directions between stakeholders, a large volume of data is transmitted, and versioning problems arise that make it challenging to track shared data. Construction cooperation has been made easier by a variety of collaboration tools, but issues with data management and governance still need to be solved (Alreshidi et al., 2018). The longitudinal, dynamic, and varied characteristics of buildings, among other things, make management of this information challenging in the context of architecture and construction. Additionally, the cost of digitising this data is considerable and it is part of a fragmented value chain (ECTP SRIA, 2019).

Diversified applications, constrained margins, a lack of cross-enterprise standards, and the development of task-specific data silos have all been shown to produce restrictions on data exchange, both horizontally, i.e. data exchange with peer stakeholders between functional areas in projects, and vertically in the construction industry, i.e., between individual building representations and neighbourhoods (Hoare et al., 2019).

2.2.2 Common Data Formats

As construction data is of concern for the thesis, it is crucial to understand and have an overview of the usual data formats and their dataset extensions that are generated, exchanged, and stored over the course of the construction project and building operations. Project participants contribute varied data formats due to their diverse specialties and data sources. Documents, forms, models, digital tools, NetCDF[1], spreadsheets, ASCII binary[2] datasets, raster, and vector data are some examples. Data ranges from kilobytes to terabytes, depending on the scale of the project.

Table 2.1 lists the different data formats with the dataset extensions that are used in a typical construction project. This helps to understand and get an overview of most of the datasets that are made or used over the life of a building.

Table 2-1: Commonly used file Formats.

Datasets	Dataset formats	Dataset extensions
Plans, digital models and blueprints	CAD drawings	.fbx, .dxf, .dwg, .dgn, .skp,
	BIM Models	.ifc, .rvt, .pln, .nwd, .nww, .stp, .ste
	3D Renderings	.3dm, .3ds, .obj, .stl, .blend, .skp, .mb, .ma

[1] NetCDF: https://www.unidata.ucar.edu/software/netcdf/
[2] ASCII, Binary: http://sticksandstones.kstrom.com/appen.html

	Documents and image files	.pdf, .txt, .doc, .docx, .jpg, .tif, .tiff, .png, .bmp, .gif, .heic
	Geospatial data	.pdf, .gml, .citygml, .kml, .geojson, .tif, .tiff, shp
	PLM data	.dwg, .mdb, .xls, .csv, .sql, .shp, .ifc
Materials and specifications	Spreadsheets	.xls, .xlsx, .gsheet, .tsv, .csv, .ods
	Relational database	.mysql, .sql, .mdf, .mdb, .accdb, .odb, .pgsql
	Structured exchange data	.json, .xml
	Documents	.txt, .doc, .docx, .doc, .pdf, .md
Schedules and budgetary data	Project management software files and gantt charts	.mpp, .msp, .pptx, .xml, .josn, .csv, .tsv, .mpt, .pdf
	Documents	.txt, .doc, .docx, .doc, .pdf, .md
	Spreadsheets	.xls, .xlsx, .gsheet, .tsv, .csv, .ods
Repairing and maintenance records for FM	Relational database	.mysql, .sql, .mdf, .mdb, .accdb, .odb, .pgsql
	Spreadsheets	.xls, .xlsx, .gsheet, .tsv, .csv, .ods
	Log files	.log, .csvm .json, .xml
	Data visualization	.html, .png, .jpeg, .xml, .xlsx, .svg, .pdf
Occupancy and sensor data for FM	Spreadsheets	.xls, .xlsx, .gsheet, .tsv, .csv, .ods
	Time-series data	.csv, .json, .tsv, .xls, .xlsx, .nc, .json
	Sensors data	.csv, .log, .bin, .json, .xls, .xlsx, .nc
	Graphs and charts	.png, .jpeg, .svg, xlsx, .xls, .pdf
Inspection and compliance records	Relational database	.mysql, .sql, .mdf, .mdb, .accdb, .odb, .pgsql
	Multimedia records	.mp4, .mp3, .avi, .mov, .wav, .aiff, .jpg, .png, .jpeg, .gif, .tiff, .tif, .heic, .mov
Weather and environmental data for FM	Meteorological data files	.tmy, .tmy2, .tmy3, .epw, .wea, .csv, .nc, .grib, .grb. .shp, .hdf5
	Time-series data	.csv, .json, .tsv, .xls, .xlsx, .nc, .json
	GIS data	.shp, .kml, .geojson, .dbf, .shx, .prj, .sbn, .sbx, .json, .gdb, .img, .grid, .asc, .bmp, .jpg, .jpeg, .png
	Graphs and charts	.png, .jpeg, .svg, xlsx, .xls, .pdf

Demographic data (for FM)	Spreadsheets	.xls, .xlsx, .gsheet, .tsv, .csv, .ods
	Relational database	.mysql, .sql, .mdf, .mdb, .accdb, .odb, .pgsql
	Text documents	.txt, .doc, .docx, .pdf
	Data visualization	.html, .png, .jpeg, .xml, .xlsx, .svg, .pdf
Property and financial data (for FM)	Spreadsheets	.xls, .xlsx, .gsheet, .tsv, .csv, .ods
	Relational database	.mysql, .sql, .mdf, .mdb, .accdb, .odb, .pgsql
	Text documents	.txt, .doc, .docx
	Maps and GIS data	.shp, .kml, .geojson, .dbf, .shx, .prj, .sbn, .sbx, .json, .gdb, .img, .grid, .asc, .bmp, .jpg, .jpeg, .png
	Data visualization	.html, .png, .jpeg, .xml, .xlsx, .svg, .pdf

The datasets mentioned in Table 2.1 are most commonly used datasets in construction sector. There could be more datasets available based on the software product and custom-specific dataset formats as per the user requirement. These datasets were sourced from the literatures and internet search portals and abbreviations are avoided as it is out of scope for the thesis.

Table 2.1 shows that most often used dataset formats are spreadsheets, relational databases, documents and data visualization. This is because of the data interoperability these datasets offer. Many software products available in market can be able to import or export the data in this format extension. It also shows that how heavily the portable document format (PDF) file format is used. It also shows that Microsoft software[3] data formats, especially Word- and Excel-file formats, are used more frequently. Surprisingly, a lot of different picture formats are used.

When working with different data formats, there are compatibility and governance issues related to things like intellectual property (IP), ownership, access rights, inconsistent data, and liabilities. Moreover, it is challenging to trace changes made to the data file when non-editable data formats like PDFs are used. As a result, it increases the risk of losing track of changes to a particular set of data (Alreshidi et al., 2018). For

[3] Microsoft: https://www.microsoft.com/de-de/microsoft-365/products-apps-servic

the purpose of assisting users in making decisions, the data may be displayed as tables, figures, or charts. According to earlier research, a central information hub is required to show the relevant digital data, such as 3D (3-dimensional) models, building characteristics, environmental data, energy consumption data, occupation data, etc., that may help users make decisions. It is anticipated that, AI might have the capacity to manage information effectively, and might use appropriate algorithms for the monitoring, evaluation, and visualization of the site objectives (Xue et al., 2022).

2.2.3 Storage of Building Data

The demand for trustworthy and safe storage technologies for construction data has risen because of a rising trend toward digitization and automated processes in the construction sector.

Alreshidi et al., 2018 conducted empirical investigation among construction industry professionals using a standardised questionnaire. Alreshidi et al., 2018 asked building site engineers about data storage methods they use. Table 2-2 outlines how construction respondents store and archive data. The construction company's network drive was preferred; paper storage ranks second; cloud and flash storage use are identical; personal computers and laptops are used to store data more than optical media. Respondents use portable external hard drives less often. Most practitioners are concerned about the limited storage capacity and IT department-restricted data access of company-hosted hard drives. To protect their data, they print it. Since enterprise IT departments restrict data access and storage capacity, cloud storage is more common than alternative methods. To avoid data loss, they print a copy. Notably, cloud storage solutions are more popular than traditional storage options (Alreshidi et al., 2018).

Table 2-2: Methods for storing the data (Alreshidi et al., 2018)

Technologies/tools	**Result Mean Index: Never 0 - Always: 5**
Paper	3.20
Optical media	2.89
Flash storage	3.11
Networked drive hosted by the company	4.27
Portable external hard drive	2.63
Cloud storge	3.00
On PC/Laptop	2.96

Over the past several years, cost-effective digital storage management solutions have emerged, and software tools have been developed to assist company managers in putting them into use. Digital information is intended to draw its value from information and business processes that employ electronic media and best practises. Nevertheless, storage and archiving are of utmost significance in knowledge platforms where information management is used. However, effective implementation of electronic storage and archiving requires on a firm knowledge of the fundamental information standards and protocols that the storage system depends on (Ko & Han, 2015).

Any system for managing electronic records and information should enable and secure long-term data storage to allow utilization of the data in the future if needed. Currently, it is economical and preferable for performance reasons to maintain all active electronic documents on a storage device. High-density magnetic tape and recordable discs are the backup media storage. These storage devices can read computer-formatted data files and directly write them on optical discs in their original format. Moving inactive documents from magnetic disc storage to tape or optical disc storage should be taken into consideration when managing large volumes of documents, particularly those maintained as page images or multi-media information like images, videos or audio data (Gyampoh-Vidogah & Moreton, 2005). At an individual construction site context, the use of increasingly sophisticated data analytics and the use of technology to guide decision-making and enhance project results is the current trend in construction data utilisation. Among the present tendencies are BIM, predictive maintenance, IoT and AI technologies (Siccardi & Villa, 2022).

BIM is a multi-functional repository that stores data throughout the course of a construction project. Throughout the whole construction lifecycle of the building, users may share and modify data more easily thanks to the digital display and exceptional interoperability features. This advantage can assist stakeholders in gathering comprehensive building data (Cao et al., 2022). BIM offers stakeholders a platform for collaborative site management so that they can combine data on the contract, quality, supply chain, etc. Construction project productivity, quality, and safety may all be dramatically increased by BIM (Chen et al., 2015).

The phenomena of cloud computing in the construction sector is relatively new. It enables a variety of technical services, including as archiving, databases, communication, servers, software, and analytics, to be delivered via the cloud, giving construction specialists access to faster and more versatile resources. The gathered data must be kept in a platform or database. These days, data sharing and storing may be done via cloud computing and BIM (Cohesive BIM, 2021).

2.2.4 Data Management Systems in Construction Sector

Throughout the lifespan of a construction project, construction DMSs are comprised of software programmes that are intended to assist construction professionals in the management, organisation, and storage of data. Worldwide there are currently around hundred DMSs are in operation. The building technology sector is continuously undergoing change, as well as the development and implementation of brand-new technologies on a regular basis.

The commercial market for construction DMSs is quite segmented, with a wide variety of businesses, both large and small, providing various solutions. Some of the popular construction DMSs are Procore[4], Oracle Aconex[5], RIB MTWO[6], Cloudbrixx Dataroom[7], Buildertrend[8], Fieldwire[9], Dassault Systemes BIM/VDC[10], Graphisoft BIMx[11], ConstructConnect[12], CoConstruct[13], BuilderStorm[14], CMiC[15], eSUB[16] and Autodesk Construction Cloud[17] products such as Autodesk PlanGrid[18], Autodesk BIM 360[19], etc. These DMS have different working principles, services and have different business models.

Some frameworks from the literature that are being developed for scientific purposes, such as CoSMoS, DDIM, and Integrated Frameworks of Smart Management, are discussed below, to give an overview of how the DMSs exchange and manage the data.

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[4] Procore: https://www.procore.com/de
[5] Oracle Aconex: https://www.oracle.com/de/industries/construction-engineering/aconex/
[6] RIB MTWO: https://www.rib-software.com/loesungen/cloud-unternehmensloesung-bau
[7] Cloudbrixx Dataroom: https://cloudbrixx.de/en/module/datenraum
[8] Buildertrend: https://buildertrend.com/
[9] Fieldwire: https://www.fieldwire.com/de/
[10] SD BIM/VDC: https://discover.3ds.com/bim-virtual-design-construction
[11] BIMx: https://graphisoft.com/de/archicad/visualisieren/bimx
[12] ConstructConnect: https://www.constructconnect.com/
[13] CoConsruct: https://www.coconstruct.com/
[14] BuilderStorm: https://www.builderstorm.com/
[15] CMiC: https://cmicglobal.com/
[16] eSUB: https://esub.com/
[17] AutodeskCC: https://construction.autodesk.com/workflows/construction-document-management/
[18] Autodesk Plangrid; https://construction.autodesk.com/products/autodesk-plangrid-build/
[19] Autodesk BIM360: https://www.autodesk.de/bim-360/

CoSMoS

Riaz et al., 2017 has proposed a protype for confined space monitoring system or CoSMoS, it presents a possibility to integrate sensor data into BIM software through new add-ins for greater visualisation. The CoSMoS database schema for storing BIM and sensor data is shown in Figure 2.2, in which the processes are described.

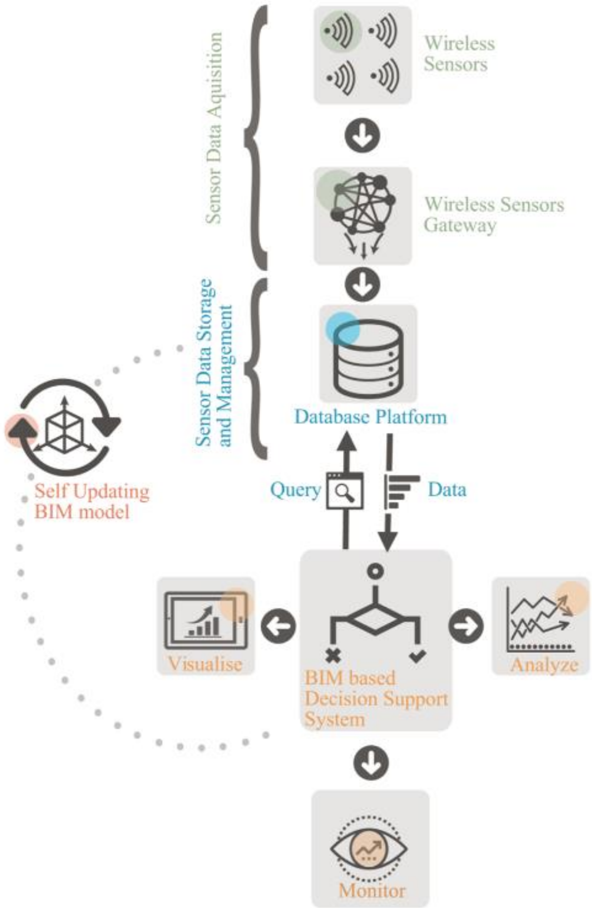

Figure 2.2: CoSMoS data framework (Riaz et al., 2017)

CoSMoS works with an ongoing stream of time-series sensor data; thus it needed a database that takes into consideration the nature of this data and grows effectively as data volumes rise (Riaz et al., 2017). In this way, the system could also improve the data management system, whether it has a broader purpose or different types of use-case specific data.

Distributed District Information Model (DDIM)

Hoare et al., 2019 proposed a contextual ontology for urban distributed data management for macro-level data collection and management. It is on the macroscopic level of the data management, but it could be imposed for the data management on one construction site by referring to the site as an urban district.

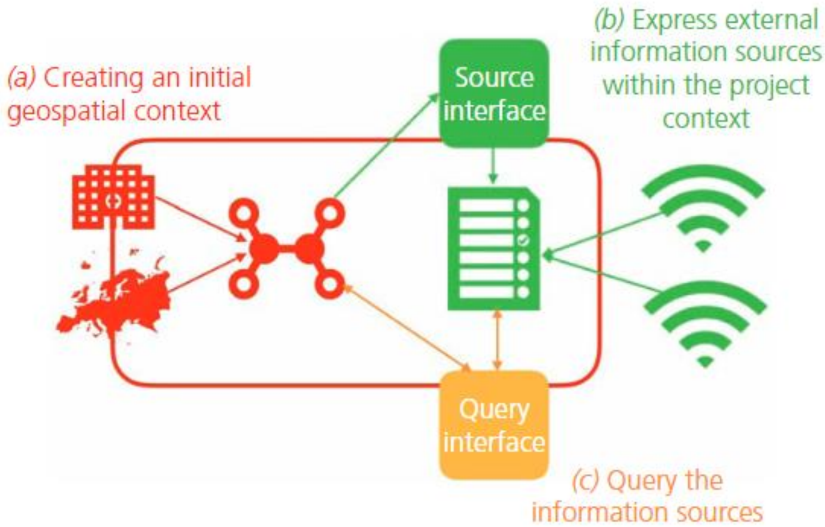

Figure 2.3: DMS for heterogeneous multiscale data (Hoare et al., 2019)

Figure 2.3 shows the three distinct processes that make up DDIM. To create a contextual model that represents both hierarchical and equivalence connections between various sources, at first it takes a variety of information sources and mines them. When sources exchange data, it is performed in a context that is suitable, as determined by the context model. In second step, the sources are listed in a DCAT (Digital Catalogue Vocabulary)[20] registry on the DDIM server, even though this data is maintained in RDF[21] format on the authors' own server. Last and third step is the creation of queries by project participants who want to access the data. These requests are made as Sparql[22] requests to the DDIM server (Hoare et al., 2019).

Integrated Framework of Smart Management (IFSM)

The goal of this research is to provide a standardised framework for data exchange in smart construction management. To create the framework Xue et al., 2022 used a two-pronged design approach that combines text analysis and semi-structured interviews. The result is a five-layer architecture for exchanging data, with functional modules for on-site monitoring, staff, safety, material, digital files, quality, environment, and supervision. This architecture is made up of perception, transmission, database, application, and presentation levels. To increase efficiency, the framework makes use of BIM, IoT technologies and cloud computing. The research gives a consistent framework for

[20] DCAT Registry: https://www.w3.org/TR/vocab-dcat-3/
[21] https://www.w3.org/RDF/
[22] Sparql: https://www.w3.org/TR/rdf-sparql-query/

identifying key components and outlining essential functions, serving as a valuable standard for data management and cooperation in different sectors (Xue et al., 2022).

2.3 Future Trend - Construction Data

There is a need for technological advancement in construction site data collection in the future for several reasons such as improved efficiency and accuracy for the construction processes, better collaboration, enhanced safety and sustainability.

As BIM is used more often in the construction industry, it is anticipated that data collecting technology integration with BIM should increase, enabling real-time updates and greater accuracy. The anticipated upcoming trends by adopting BIM for the data collection on construction site are digital twin, use of AI, robots could be on site for construction site data collection etc. (MagiCAD, 2022). Real-time data on construction sites are predicted to be more in demand as it enables quick decision-making and enhanced stakeholder communication. Data collection technologies would be increasingly be integrated with other systems, including as safety management systems and equipment tracking systems, to provide a more thorough picture of construction site activities (Rao et al., 2022). It is likely that mobile software and apps might be used more to collect, analyze, and manage data on-site. New trend to use the wearable technology, such as smart watches and eyewear, to track worker activity and safety. Using drones, it is easy to take visual of the progress on site and to collect the data on regular basis. The framework with BIM can compare the progress on regular basis. RFID enabled construction material tracking accelerates the material positioning and usage on site details (Edirisinghe, 2019).

Looking to the current state of the art for technological advancement for the storage of data in all sectors and particularly in construction sector, it is significant to know that, in coming years construction sector adopting the technologies such as BIM, AI and machine learning for the automated operations, blockchain for smart contracting, 5G for effective and speedy data transmission etc.

Figure 2.5 exhibits the five trends that might shape the future construction sector. These five concepts are realistic or not particularly far-fetched. All of them have their origins in technological advancements that may be used in the building industry and are either in use or have been prototyped. In a summary, they are essential and useful. Additionally, they are created to collaborate in order to have a stronger influence (Agarwal et al., 2016).

Figure 2.4: Five trends for construction projects (Agarwal et al., 2016)

The future technical advancements for storing information from building sites includes the AI and machine learning are forecasting the schedules, managing the processes etc. on construction site. It is anticipated that the application of AI and machine learning in data analysis and storage would grow, resulting in more sophisticated insights and better decision-making. For instance, a new generation of tools that enable businesses to continually monitor their heavy equipment on site in real time is powered by machine learning technology. The system proactively warns the operator if any component fails or malfunctions, therefore enhancing worker and site safety (Gopal, 2019).

On construction sites, the usage of IoT devices is anticipated to increase, and the data these devices produce is anticipated to be saved and analysed in real-time. VR and AR technologies are anticipated to be utilised more often in the construction industry, and the data produced by these technologies is anticipated to be kept and analysed to aid in decision-making (Davila Delgado et al., 2020). The usage of blockchain technology in the construction industry is expected to grow since it offers a safe and decentralised method of storing and accessing project data. Supply chain management (SCM) and BIM are two important fields where blockchain technology may have a more profound and immediate impact (Al-Smadi et al., 2023). The rollout of 5G networks is anticipated to boost data transmission capacity and speed, enabling more effective and current data storage and retrieval in construction industry (Thales, 2022).

At the macro level, construction and building data are critical pillars of a smart city's future development throughout the process. Data is the source of all information in the big data era, and in order to get valuable information, individuals would analyse and process the data. The construction of a smart city involves many vital links and gathering data and extracting information is the key factor in advancing the city's progress towards intelligence (Liu et al., 2020).

In overview of the future trends for data storage, the application of technologies is predicted to characterise the future of data storage for construction site, resulting in enhanced data analysis and decision-making. In the following subsections, future data utilization trends and new technologies are discussed.

2.3.1 Future Need for Advanced Technologies for Construction Industry

Advanced technology is needed on construction sites for a number of reasons that have already discussed in previous sections. There are many different project-related assets that move on construction sites, including building materials, machinery, and personnel who constantly interact with one another. The traditional site management methods have number of problems which leads to inefficient progress (Nakanishi et al., 2022). Monitoring the entities and providing correct asset movement statistics become increasingly difficult as sites get bigger and more complex with up to tens of thousands of active entities. Modern sensing technologies have been developed to autonomously track things and produce real-time information on their spatial positions over time in the goal of effective monitoring of such complex environments (Park & Brilakis, 2015).

A speedier and more efficient construction process is made possible by cutting-edge technologies like drones, 3D printing, and building information modelling (BIM), which also serve to streamline construction procedures and boost production. The most well-known technologies that have undergone thorough examination include GPS (Global Positioning System), RFID (Radio Frequency Identification), and UWB (Ultra-Wideband). However, their use is restricted on large-scale, crowded building sites due to the size and complexity of the site as well as the cost of installing, maintaining, and decommissioning tags or sensors on entities (Park & Brilakis, 2015). Using the mobile devices on construction site, construction workers and engineers can access information in real-time. The better access, organisation, security, and cooperation that these digital methods of data storage offer make building operations more productive and successful. In order to provide more productive and efficient building operations, these digital techniques of data storage increase access, organisation, security, and cooperation (Edirisinghe, 2019).

The risk of accidents and injuries can be increased in risky environments like construction sites, but modern technology like wearables, drones, and safety management software can assist (AL-Sahar et al., 2021). For the enhancement of the accuracy, by utilising cutting-edge technology, it is able to forecast building performance more accurately, seeing potential problems earlier, and make adjustments before construction starts, lowering the likelihood of expensive errors (Akinosho et al., 2020).

In regard to the sustainability, the construction sector may become more sustainable by using cutting-edge technology to assist minimise waste and enhance building performance. Where there is crunch in labour market, by minimising the need for human labour and increasing the precision of project planning, the adoption of sophisticated technology can assist lower construction costs (Hossain et al., 2020).

To estimate the progress of construction projects and detect potential dangers during operation, predictive analytics techniques are being deployed. IoT is being used to gather real-time data on construction sites and enable data-driven decision-making. After commissioning of the building, the IoT sensors are used for the building operations. Real-time data capture and information access are made possible by the usage of mobile devices in the construction industry (Kharbouch et al., 2022).

Construction personnnel management, procurement management, and real-time safety management systems are just a slew of prospective context-aware construction site scenarios that Edirisinghe, 2019 has proposed using smart, sophisticated sensor technology. The three layers that make up the proposed digital skin structure are,

1. Hardware: Hardware parts of digital skin include sensors, tags, wearables, tablets, digital assistants, bots, smart phones, personal computers, and any device with a chip or embedded chips that can detect a context parameter and talk.
2. Communication technologies: The parts of the digital skin communicate with each other from different places on the site and eventually over the internet using different network technologies.
3. Software, middleware or applications: Depending on the needs of the application, these components give the digital skin computation, visualization, analytics, analysis, storage, AI, and cloud computing capabilities.

In conclusion, the adoption of cutting-edge technology in the construction industry is motivated by the desire for enhanced cost-effectiveness, accuracy, and safety. If data properly collected, stored, and used for the continuous optimization of the construction processes, then it has enormous potential for increasing efficiency and sustainability in the construction industry.

2.3.2 Future Data Utilization

With a variety of usecases that are anticipated to have an influence on every area of the building process, the future of the utilization of construction data is bright. Furthermore, data ecosystems like Gaia-X have the potential to host this data for use in the construction industry and beyond.

Here are some usecases related to the construction and buildings discussed, in which the collected and stored data could be useful. Some of the usecases are also related to the usecase processes in project iECO, which is discussed in detail in Chapter 4.

Quality Control: It refers to the utilisation of data from sensors, drones, and other sources to continuously check the correctness and defect risk of building activity. For instance, sensors and drones may monitor building sites in real-time, informing staff members and managers of any flaws and enabling fast rectification (Duarte-Vidal et al., 2021).

Predictive Maintenance: It uses data from IoT sensors and other sources to forecast when equipment and machinery needs repair, lowering the chance of unanticipated downtime and boosting productivity. In construction sector the machinery would be termed as buildings, construction sites, infrastructures etc. Additionally, predictive maintenance can increase equipment longevity, lower the cost of replacements and maintenance, and better allocate resources (Achouch et al., 2022).

Documentation: Automated documentation for various processes and important documents such as bill of quantity, change order reports, invoices, commissioning documents, safety documents, material take-off documents could be generated using the data available for the construction site. In future these documents could help to predict the repairing and maintenance costs. The processes also could be automated using the trained AI-algorithms (RIB iECO, 2022).

Planning and designing collaboration: It is the practise of enhancing cooperation and communication between the various teams engaged in the design and construction process by using BIM and other data-driven technologies. For instance, BIM gives many teams a single workspace to collaborate on, lowering the chance of mistakes, enhancing accuracy, and boosting overall effectiveness (Abbasnejad et al., 2021).

Resource optimization: It is the process of using data to allocate resources efficiently, reduce waste, and boost overall project effectiveness. To better allocate resources, data analysis might, for instance, show where building materials are being used excessively or insufficiently (Zaneldin, 2008).

Real-time construction site monitoring: It refers to the practise of using drones and other sensor-equipped equipment to keep an eye on work sites and gather information on their conditions, worker safety, and material use. Real-time monitoring may speed up and accurately complete construction projects more quickly, cut down on waste, and increase safety (Rao et al., 2022).

Safety monitoring: Monitoring worker safety and wellbeing using data from wearable technology and other sources to lower injury risk and increase overall safety. Wearable technology, for instance, may track employee weariness, encourage employees to take breaks, and warn managers of possible safety risks (Patel et al., 2022).

Supply chain management and optimization: It is the process of using data to streamline the movement of supplies and resources along the whole supply chain for the building industry, therefore cutting waste and boosting productivity. For instance, supply chain bottlenecks may be found via data analysis, which can improve delivery times and save prices (Fernando, 2022).

These usecases are a handful of the numerous ways in which data could influence the construction sector in the future. The potential advantages to the construction sector are projected to increase as data becomes more common and sophisticated, resulting in better project results and lower costs. It is foreseen that broad use of data-driven tools and technologies to raise the precision, effectiveness, and safety of building projects defines the future of the use of construction data. Furthermore, potential usecases for data utilization are discussed in Chapter 7.

3 Simplified Context of Gaia-X Sovereign Data Ecosystem

Project Gaia-X was presented in October 2019 by the German and French ministries of economic affairs, and officially, the Gaia-X European Association for Data and Cloud AISBL was established as a non-profit organization in January 2021 in Brussels. The project's name refers to the Greek goddess “Gaia”. Gaia-X Association currently has over 320 members from all over the world, who contribute to create a transparent, sovereign and secure data ecosystem. Gaia-X is founded on European ideals such as transparency, openness, data security, and privacy. Gaia-X Hubs represent user ecosystems nationally. They combine national efforts, build ecosystems, and serve as a hub for interested parties in their country (BMWi-19.10, 2019). A federated and secure data infrastructure ecosystem is being created by industries, politicians, academicians, and scientists from Europe and throughout the world.

Data is frequently dispersed and "siloed" according to business processes, making it difficult to exchange data, even within a single firm. It is much more unlawful when partners exchange data (Ladid et al., 2021). In order to achieve transparency, interoperability and sovereignty across data and services, Gaia-X is a project to provide an open software layer of control, governance, and the application of a standard set of policies and regulations to be applied to any current cloud or edge technology stack. Any cloud participant that implements this open software layer together with the related policies and regulations can use this to deploy the system (Bonfiglio, 2021).

In this chapter, the Gaia-X ecosystem is simplified. To understand the concept of the Gaia-X ecosystem, the technical and operational architecture with adjoining entities are discussed. They might not be related to the overall goal of the thesis, but they are necessary for comprehension. There are too many terms being used during the explanation. The glossary on participants and roles, as well as other entities related to the Gaia-X ecosystem, are listed in Section 3.3.2.

3.1 Goals and added value of Gaia-X Data Ecosystem

The Gaia-X ecosystem lays the path for a digital infrastructure that is flexible, dependable, and built on European principles. Organizations would profit from the project, which could also provide a new degree of trust for cooperation within and across data spaces. A user-friendly, open, and transparent digital ecosystem for innovations is created by Gaia-X through the establishment of a trusted environment between partners and interoperable connections between smart service apps and infrastructure services. In compliance with the laws now in effect in the EU and its member states and based on accreditation and policy enforcement, Gaia-X permits a free, yet safe and auditable, flow of data. Gaia-X prioritizes data sovereignty and choice. Data providers manage their own data, and consumers trust them to provide trustworthy data through Gaia-X. Users can pick services that satisfy their requirements for robust information security, legal certainty under the European General Data Protection Regulation (GDPR), data storage in specified countries or regions, or other specific qualities (BMWi PR, 2020).

Gaia-X promotes the development of digital ecosystems that may be used for business purposes within and beyond various domains. It targets a variety of target groups, such as customers, providers, and facilitators like the public sector or academia, and drives value, business cases, and innovation toward them. The Gaia-X data and infrastructure ecosystem adds value to the exchange of data and services within and between domains, even when provider and customer boundaries are taken into account.

In traditional data ecosystems, data providers and consumers have little or no control over their data, which means they have no idea where and how it is stored or who is going to use it.

3.2 Gaia-X Dataspace

A data space's fundamental objective is to enable the independent and safe interchange of data among participants in a "trusted ecosystem" (Ladid et al., 2021). In the context of Gaia-X, a dataspace is a platform that offers a unified and decentralized method of storing, processing, and managing data. Within the Gaia-X ecosystem, dataspaces serve the objective of developing a safe, reliable, and user-centered platform for data management that is based on open standards and technologies. In terms of functionality, it should be stated what values and traits a dataspace should uphold, including confidentiality, data ownership, and accessibility. Additionally, Gaia-X plans to develop a governance structure for the dataspace that emphasises stakeholder cooperation and decentralisation. The governance model places a strong emphasis on the value of cooperation among diverse ecosystem participants, including data owners, service providers, and data consumers (Kraemer, Niebel, et al., 2022).

In the Gaia-X ecosystem, dataspaces offer a wide range of advantages. For instance, with Gaia-X dataspaces, the potential advantages for numerous industries, such as improved innovation and competitiveness. Business organizations would have access to a large pool of data thanks to dataspaces, enabling them to create new goods and services. The introduction of dataspaces also encourages international data sharing and the growth of new business models (Otto et al., 2021). The use of dataspaces in Gaia-X has the potential to transform industrial sectors and foster international data collaboration and exchange. Dataspaces may advance a safe, dependable, and user-centric platform for data management by adhering to principles like privacy, data ownership, and accessibility (Otto et al., 2021).

Dataspaces can enhance data privacy and protection in the construction industry. Sensitive information about buildings should be protected from illegal access using secure, decentralized data storage. Building owners and construction businesses could also be able to exchange building data more readily, which might improve building operations. As data owners have more control over how their data is used and who may access it, it is anticipated that dataspaces would enables a more equal distribution of the value created by data. For example, in the construction sector, project iECO creates a iECO dataspace and enables owners, contractors, etc. to store and trade data. Moreover, Gaia-X dataspaces are discussed in Section 7.3.

3.3 Gaia-X Federated Data Ecosystem

The virtual group of participants and service providers adhering to the Gaia-X standards from the Gaia-X Trust Framework is known as the Gaia-X Ecosystem (GX-TRF-22.04, 2022). Gaia-X serves as the foundation for collaborating and deploying trustworthy technologies with aim of scaling through federation. A single EU market that enables any participant to transact digitally inside the EU with little resistance might strengthened as an outcome. Digital platforms are becoming more like real world's economic, political and cultural ecosystems (Bonfiglio, 2021). The open, transparent, sovereign, fair, independent, inclusive, free, federated, inventive, and evolving data ecosystem is based on the 10 fundamental principles of the EU that make up this ecosystem.

3.3.1 Gaia-X Architecture

Gaia-X Data Ecosystem

In an interactive ecosystem, Gaia-X connects individuals, organizations, and resources by using a federated method to provide a broad basis for data access and sharing. It makes sure that the operating guidelines and legal framework for data spaces adhere to the EU data policy. This enables the development of advanced smart services (SAS) like big data apps and marketplaces, which encourage innovation within and across sectors. It encourages the possibility of working together in data-driven vertical and horizontal value chains. Additionally, by giving small and medium enterprises (SMEs) and start-ups the same possibilities to use big data to their advantage in order to expand in the digital sphere, it lessens the fragmentation of the international market. This encourages the development of resilient business and innovation ecosystems for the coming wave of digital infrastructure (BMWi PR, 2020).

As provided in Figure 3.1, the SASs and data spaces enable different fields and services to leverage the benefits of the Gaia-X data ecosystem through cross sectoral innovations and interoperability between datasets and services. The Gaia-X data ecosystem supports ontologies for interoperability and APIs across and beyond sector-specific dataspaces, such as mobility with industrial, smart living with skills, and so on. This facilitates the implementation of SASs such as AI, IoT, big data, and so on (BMWi PR, 2020).

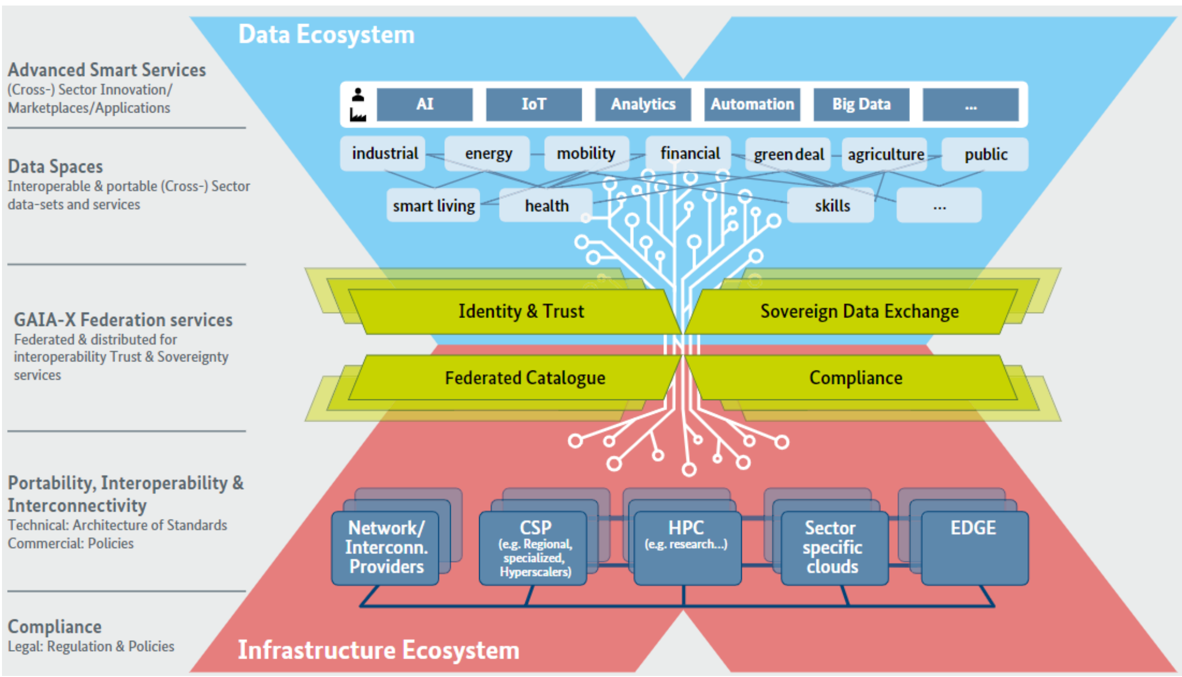

Figure 3.1: Overview of Gaia-X ecosystem (BMWi PR, 2020)

Framework for Collaboration

Mechanisms for data processing and sharing between various parties are made possible by Gaia-X. This makes it possible for businesses across all sectors and sizes to manage their data assets with confidence. This is motivated by European ideals rather than being constrained by geopolitical bounds. Data sovereignty is maintained while enabling secure data sharing and facilitating data interchange in business ecosystems built on standards and shared governance structures. The data ecosystem serves as the foundation for intelligent services and cutting-edge business procedures while also protecting the owner's digital sovereignty (BMWi PR, 2020).

Figure 3.2 provides an overview of collaboration in current time and future collaboration through Gaia-X. In today's collaboration, data and infrastructure are not centralized and specific to the company, resulting in data silos; however, in the Gaia-X ecosystem, there is dedicated data and infrastructure where companies participate through GXFS functionalities and data is stored in different data storage as the company wants.

This can aid comprehension of the demonstration of the project iECO usecase process integration with GXFS in Chapter 6 and how the GXFS is involved in the usecase process.

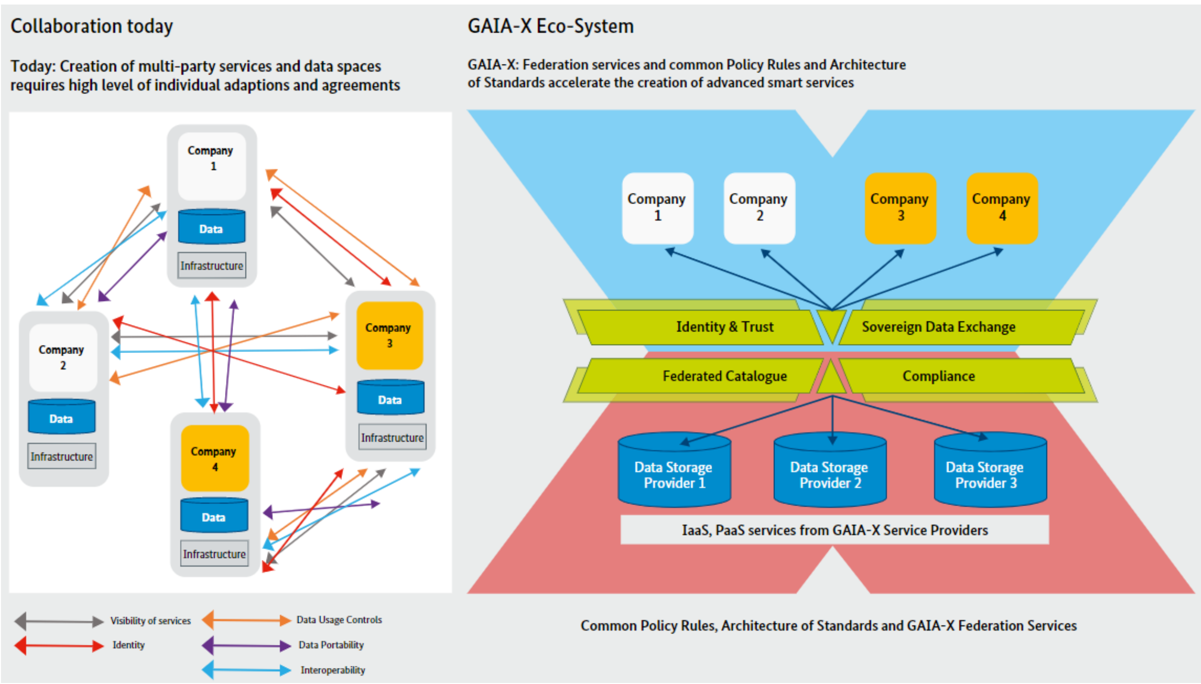

Figure 3.2: Collaboration today and in future through Gaia-X (BMWi PR, 2020)

Gaia-X Federation Services (GXFS) for the Federation of Ecosystems

Data is the key building block for innovation and the creation of smart business applications and services. Data value chains are necessary for the innovation of different industries and markets. They are a result of the SAS's collection of data from sensors, devices, goods, etc. and involve their pre-processing, storage, and transmission for analysis. The GXFS create a secure link between established and developing infrastructure and data eco-systems. It enables or disables the analysis and linking of data. According to publicly defined regulations and standards, access to data by other parties may be restricted or permitted. Regarding third-party digital infrastructure, data sovereignty can also be ensured e.g., through interconnection, the cloud, or software (BMWi PR, 2020). Moreover, GXFS is explained in Section 3.6.

Gaia-X Infrastructure Ecosystem

In technical terms, Gaia-X makes it possible to manage and use the trustworthy, secure, and federated infrastructure required to support data sovereignty and self-determined processing and storage. It operates as the foundation for the creation of data and service eco-systems, enabling seamless data and service interaction and fostering creative digitalization usecases at the corporate level. Gaia-X creates an infrastructure ecosystem by establishing portability and interoperability across network and interconnection providers, sector specific clouds, cloud solution providers[23] (CSP), high performance computing[24] (HPC), and edge systems[25] (See Figure 3.1).

Gaia-X supports dispersed application instances as a federated data infrastructure, including on-premise configurations, cloud-hosted infrastructure, and facility-to-edge scenarios. Gaia-X must therefore manage the whole technical stack, including infrastructure and existing network/interconnection demands (i.e., standards architecture of dispersed usecases), such as responsiveness and privacy requirements of the connected network (BMWi PR, 2020).

[23] CSP: https://www.techtarget.com/searchitchannel/definition/cloud-service-provider-cloud-provider
[24] HPC: https://www.bigdata-insider.de/was-ist-high-performance-computing-hpc-a-943437/
[25] https://www.intel.de/content/www/de/de/edge-computing/edge-devices.html

3.3.2 Gaia-X Terminologies

Gaia-X ecosystem's conceptual model and architecture involve many functional and technical terminologies and roles. For example, the participant that is involved in the process has some roles, and based on those roles, they can have different access rights. Some components are involved in the Gaia-X ecosystem, which also has functions to enable function-specific roles. The following Table 3.1 lists all the terminology related to the Gaia-X conceptual model and architecture, along with their abbreviations and brief definitions.

Table 3-1: Terminologies of Gaia-X Architecture (GX-TAD-22.10, 2022)

Term	Short Form	Description
Participant	PR	A Participant is a legitimate individual or organization that may play one or more of the following roles: Provider and/or Consumer
Provider	PPR	Participant is in charge of providing an asset to the Gaia-X ecosystem.
Federator	FR	Federators are organizations with the legal right to administer a number of FSs for a particular federation in accordance with Gaia-X standards and guidelines that are under the AISBL's supervision. The Federator may be an AISBL itself. A Federator oversees Participants for its federation, delivers notifications to Participants, ensures QoS of the catalogue, and can provide an API Gateway to expose publicly accessible Gaia-X APIs. It also validates participants' requests for accreditation.
Federation		Federations are autonomous ecosystems where different participants collaborate to produce services that may be used only within the Federation, therefore adding value to the participants as well as to the market (GXFS - eco e.V., 2022).

Consumer	PCR	A Gaia-X participant's responsibilities include interacting with users and devices, looking for and buying services, and keeping up commercial relationships with providers. Service instances are consumed by a consumer, but they may also be made available to their end-users.
Visitor	VR	An unregistered entity (human, robot, etc.) browsing the Gaia-X catalogue.
Issuer		The issuer is the authority that issues the credentials to PR. Gaia-X context, the credentials are, for example, DID (Decentralized Identifiers), etc.
Natural Person	NP	Natural person can participate in Gaia-X as VRs or PRs. In order to participate, a person must be accredited by one of the member organizations or by the AISBL, which serves as the federator for requests for accreditation from unaffiliated natural persons.
Resources		In general, resources describe the goods and objects of the Gaia-X Ecosystem. Resources can be physical, virtual, or instantiated virtual resources.
Service Offerings	SO	A "service offering" is a collection of resources that a provider gathers and makes available as a single application in a catalogue. A service composition can be made by combining several service offers.
Self-Description	SD	See Section 3.5.3 for a detailed explanation on self-descriptions.
Service Instance		At runtime, an SO is created as a service instance, and it can only work with a certain version of a SD.
Claim		In VC context, a claim is statement about a subject.
Verifiable Credentials	VC	A collection of claims that have been authorized by their issuer.
Participant Credentials	PC	PC is approved organization VC which is signed by Gaia-X AISBL

Verifiable Presentation	VP	VP is an aggregation of VCs.
Verifier		The verifier is an instance or service provider that verifies VP.
Contract		A "contract" is an agreement between a customer and a provider that permits and regulates the usage of one or more service instances. It is linked to a particular version of a service, and it uses that version to determine the characteristics of the service instances that need to be supplied.
Policies		A policy is defined as a declaration of goals, guidelines, procedures, or rules that direct participants' actions inside Gaia-X. Technically speaking, policies are declarations, rules, or assertions that outline the proper or anticipated behaviour of an organization.
Trust Anchor	TAR	See Section 3.5.4 for a detailed explanation on trust anchor.

3.4 Gaia-X Conceptual Model

The Gaia-X Conceptual Model outlines each topic covered by Gaia-X as well as their interconnections (GX-TAD-22.10, 2022). Different Gaia-X actors are depicted in the model's top portion, while components of commercial trade and the relationship to other players are shown in the model's lower portion. When an element is highlighted in blue, it means that it is a part of Gaia-X and is consequently subject to the Gaia-X SD. See Attachment A.1 (GX-TAD-22.10, 2022) for the conceptual model for the Gaia-X. The relationship between various entities, such as participants, is readable by the legend given on the connection line for the Gaia-X ecosystem realisation.

Service Composition Model

The focus of the composition model is on the functional behaviour of the service, free from limitations, localization, and predetermined values for non-functional features. Only when the final users, renters, or customers have voiced their needs, restrictions, and preferences are values determined. Certain variables are gradually set as service composition transitions from initial provisioning to service life cycle management (LCM) at run time. A high-level class diagram perspective of the service composition model is shown in Attachment A.2 (GX-TAD-22.10, 2022).

The requirement for a service discovery service that can search, match, and choose from a service catalogue is shown in Figure 3.3. Depending on the customers' aim to integrate service offerings from many sources with confirmed interoperability and compatibility features accessible in the catalogue itself, the search may be concerned with other catalogues and offers. End users or renters make this initial demand and specify their expectations and limitations. Figure 3.3 contains additional steps and processes.

The service composition model analyzes, parses, and decomposes the service request. It then builds service discovery queries to search for and choose candidate services from GXFS. After the user negotiates and approves the selected services and providers, candidate services are returned to service composition for deployment and instantiation processes and plans. Contracts are also made. Service binding with providers' supplied resources begins with the service composition module's functional solution (GX-TAD-22.10, 2022).

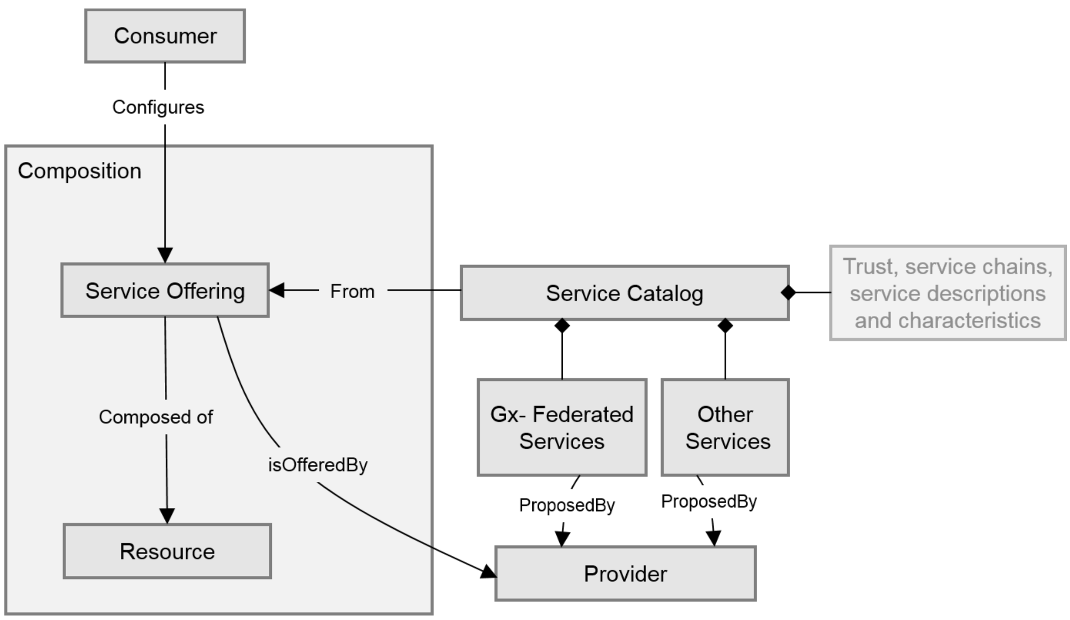

Figure 3.3: Conceptual service composition model (GX-TAD-22.10, 2022)

The Gaia-X services composition process ends with this abstract implementation plan, which providers must use to implement. An orchestrator coordinates and deploys service instances, configures and activates them, and binds and connects them. The orchestrator controls, configures, and adapts service instances using deployment and configuration tools. The Catalogue and service offers provide these tools and management systems. Cloud infrastructure deployment and configuration employ terraform[26], ansible[27], heat and salt sack[28]. An intermediate container orchestration and management system like Kubernetes[29] is used to host service instances and resources in containers instead of virtual machines. This paper and the Gaia-X service composition mode and ecosystem exclude these intermediary phases (GX-TAD-22.10, 2022).

Attachments A.1, Attachment A.2 and other process diagrams in this chapter are not detailed because it is beyond the scope of the thesis topic, but the processes are depicted in diagrams.

3.5 Gaia-X Operational Model

In order to be sustainable and scalable, Gaia-X needs an operational model that can be widely adopted by SMEs, start-ups, and big organizations, particularly those in highly regulated industries (GX-TAD-22.10, 2022).

3.5.1 Gaia-X Trust Framework

The collection of guidelines known as the "Trust Framework" establishes the minimal requirements for participation in the Gaia-X ecosystem. Requirements such as the minimum degree of syntax consistency, schema validity, cryptographic signature validation, attribute value consistency, and attribute value verification with regard to SD (GX-TAD-22.10, 2022). These guidelines make sure that all ecosystems have the same rules and basic levels of interoperability, while giving consumers full control over their choices. The trust framework creates a FAIR (findable, accessible, interoperable, and reusable) knowledge network of verifiable claims using verifiable credentials (VCs) and linked data representation, from which additional trust and composability indices may be automatically calculated (GX-TRF-22.04, 2022).

3.5.2 Gaia-X Labelling Framework

The SD-based trust structure serves as the foundation for the labelling framework. This guarantees that all the information needed to competently choose between services is

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[26] Terraform: https://www.terraform.io/
[27] Ansible: https://www.ansible.com/
[28] Heat and Salt Stack: https://salt-formulas.readthedocs.io/projects/openstack-salt/en/latest/develop/quickstart-heat.html
[29] Kubernetes: https://kubernetes.io/de/

provided in a uniform, standard manner that is machine-readable. The criterion list combines the rules and specifications from the committees' policies and rules, technical, data space, and business committees, as well as extensive verification techniques to guarantee that these specifications may be satisfied. It enables even more service differentiation, which is essential for consumers looking for services to meet their varied wants and goals. It establishes minimal standards for the qualities mentioned in the transparency framework (GX-LC-22.04, 2022).

3.5.3 Gaia-X Self-Description (SD)

Gaia-X SDs are machine-interpretable descriptions of entities from the Gaia-X conceptual Model. This covers the participants' own SD as well as the providers' resources and service offers. A single representation of the SDs is ensured by well-defined SD schemas (which the federations may adapt for their area). The SD can be used to find and compare Gaia-X entities. (GX-TAD-22.04, 2022).

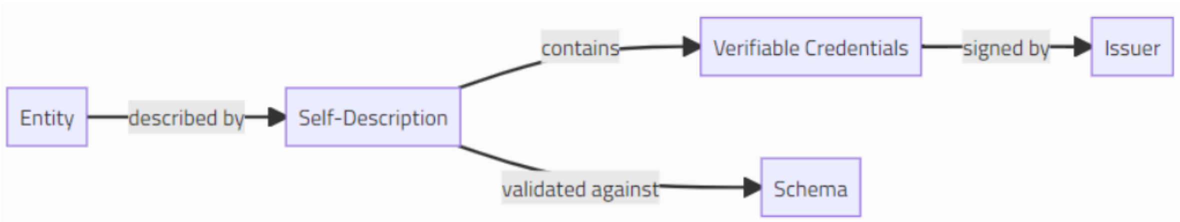

Figure 3.4: Overview of self-description (GX-TAD-22.04, 2022)

SDs are important in Gaia-X to give the introduction of the services or any participant. The GXFS tool, SD Tooling (See FS08 in Table 3-4) can generate the SDs compliant with the Gaia-X ecosystem. To see a demonstration of the SD schema, visit to the Delta-dao portal[30], which offers the first Gaia-X Web3 ecosystem[31]. Provider-side view for the SD of RIB Software AG as an example is demonstrated here. See the Link[32] here. This way consumers, providers, services etc. have their unique SD. Figure 3.4 shows in a simple way how SD works with entities, VCs, issuers, and the SD schema.

Structure of Self-Description

[30] Delta-dao Demo: https://www.delta-dao.com/de
[31] Web3 ecosystem: https://portal.minimal-gaia-x.eu/
[32] RIB Self-Description: https://delta-dao.com/.well-known/participantRIBSoftware.json

SDs are W3C-verified presentations in the JSON-LD[33] format. A set of VCs forms the SD. A collection of claims, assertions about entities is included in VCs, which are statements represented in the RDF[34] data paradigm. Cryptographic signatures are included with VCs and verifiable presentations to raise the level of confidence (GX-TAD-22.04, 2022).

Self-Description Schema

SD-Schema is a group of data structures used by classes that describe Gaia-X entities. Each data schema is a fragment of an inheritance hierarchy with participants, service offerings, or resource super-class schemas at its top. These super-class schemas each provide a set of attributes that may be used to describe the entity. SDs must adhere to a standard form and semantics. Only in this way can it be guaranteed that entities within Gaia-X can be located and compared. SD schemas provide a formal description of this structure (GX-TAD-22.04, 2022).

Collection and Verification of Signed Claims of Self-Description

The initial stage is to gather VCs. Claims may either be self-signed using a keypair provided by a trust anchor (TAR) or directly signed by a TAR. Claims may be self-signed or externally signed by a TAR using a keypair provided to the author of the SD by one of the TARs (GX-TAD-22.04, 2022). Figure 3.5 provides the workflow of collecting the signed claims from various participants and transferring them to VCs wallet.

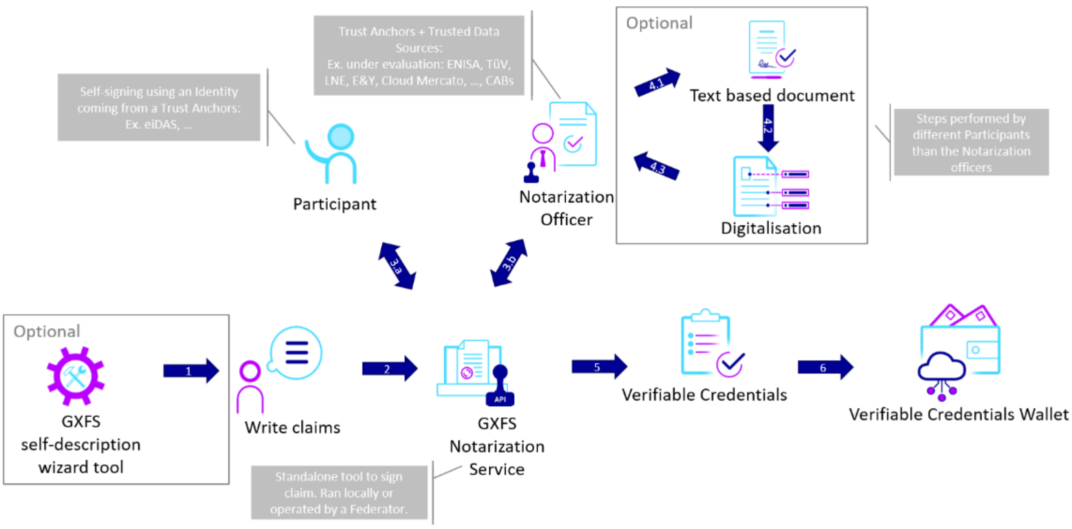

Figure 3.5: Collecting signed claims (GX-TAD-22.04, 2022)

[33] JSON-LD: https://json-ld.org/
[34] RDF: https://www.w3.org/RDF/

A participant can submit signed claims for verification to the Gaia-X compliance service using the gathered signed claims (Figure 3.6), and they will receive a signed claim consequently (GX-TAD-22.04, 2022).

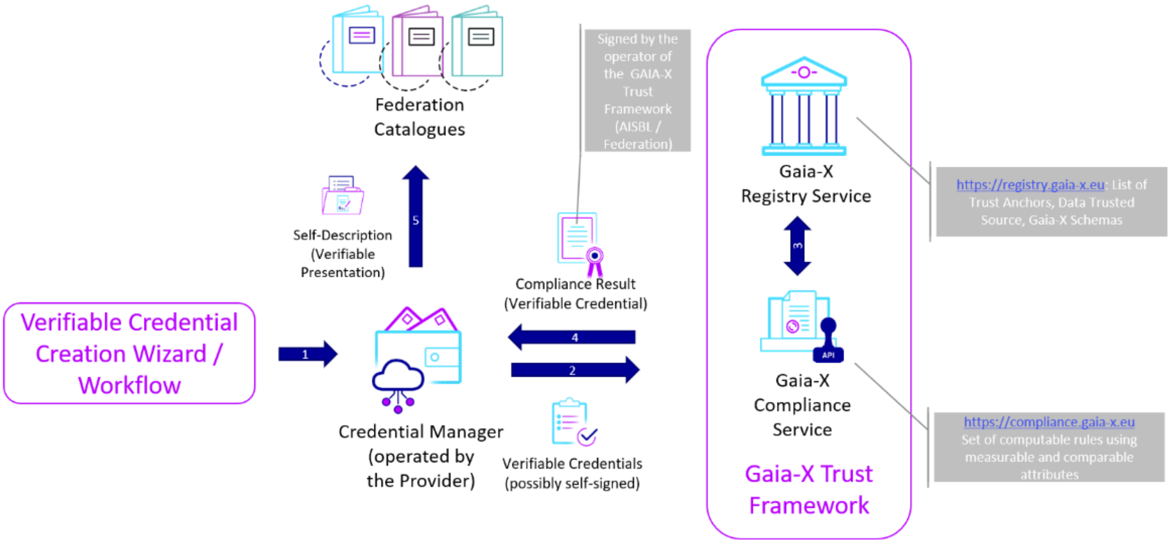

Figure 3.6: Gaia-X Verification of signed claims (GX-TAD-22.04, 2022)

3.6 Gaia-X Federation Services (GXFS)

The GXFS are essential for enabling a federation of data and infrastructure and for facilitating interoperability across federations (GX-TAD-22.10, 2022). Gaia-X wants to encourage innovation and data sovereignty. This is accomplished by creating a digital ecosystem in which data is made accessible, gathered, and distributed in a reliable setting while data owners maintain complete control over their data. The establishment of so-called Gaia-X Federations in the marketplace is made possible and encouraged by Gaia-X (GXFS - eco e.V., 2022).

Gaia-X doesn't run its own business on the market to take on established players. Associations do not establish businesses similar to independent cloud service providers, nor do they set up data rooms to collect information from their members. Instead, Gaia-X creates the software elements required to build up a federated system that links many participants with one another with the goal of creating new services and cutting-edge goods. These ecosystems are made up of linked, interconnected data and infrastructure ecosystems that are grouped together into so-called "federations" and individually coordinated and run with the aid of GXFS.

GXFS's main objectives are to offer data sovereignty, allow and promote resource interoperability, and promote portability within and between Gaia-X-based ecosystems.

They give mechanisms for data sovereignty in a distributed ecosystem, provide trust between or among participants, make resources accessible, discoverable, and consumable, and ensure trust between or among participants (GX-TAD-22.04, 2022).

3.6.1 Function of Federation Services for the Ecosystems

The relationship between GXFS instances, participants, the federator, and the compliance framework is depicted in the conceptual model shown in Figure 3.7. With the requirement of certain FS instances from FS providers, the federators make federation of services possible. The FSs are made up of all FS instances.

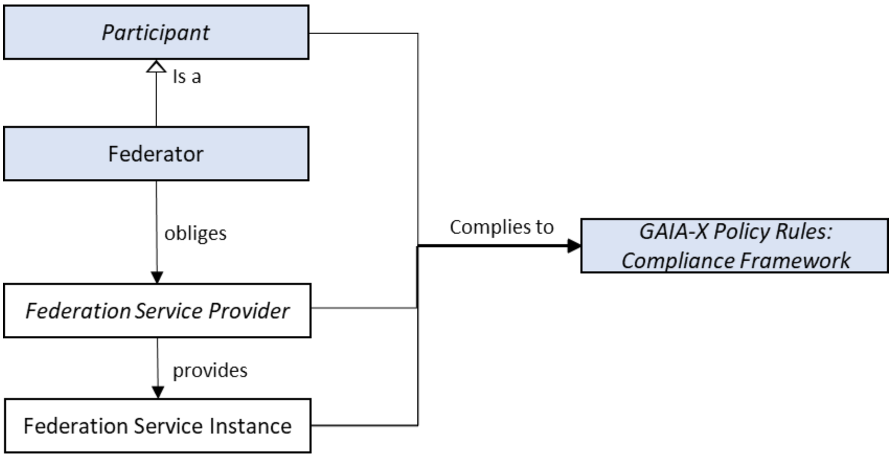

Figure 3.7: Federation services relations (GX-TAD-22.10, 2022)

3.6.2 Coupling of Gaia-X Federation Services

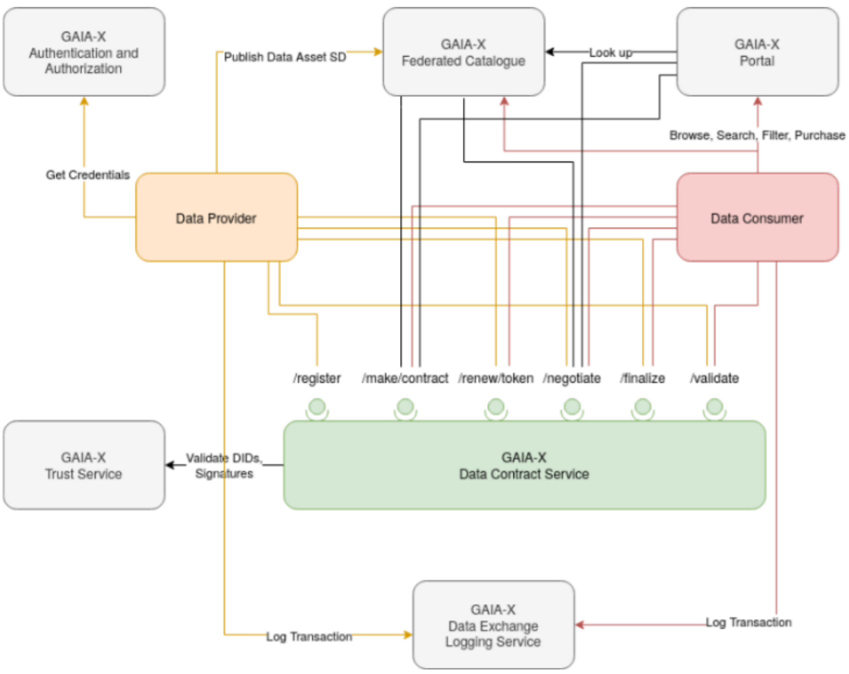

Figure 3.8: Functional overview of FS DCS (SDE.DCS, 2021)

Different Gaia-X FSs are generally coupled with other relational FSs. For example, in Figure 3.8, the Data Contract Services (DCS) is coupled with at least five other FSs. This coupling is achieved through the use of defined sharp cut infaces. One can realize this kind of GXFS coupling with other FSs. The integration of the FSs benefits Gaia-X providers and consumers by allowing them to use the Gaia-X environment and making their services interoperable more efficiently.

3.7 GXFS Toolbox

It's crucial to realize that the GXFS won't be offered by a single entity, but rather by each federation using the GXFS toolbox's standard open-source code to create applications and services that correspond to their own needs. To facilitate inter-ecosystem compatibility, the GXFS source code should be seen as a reference implementation point in any situation. Other implementations that adhere to the Gaia-X technical and functional standards may also be used to accomplish the functional implementation.

The decentralized services are to be used to verify a Gaia-X service's ultimate compliance, eliminating any opportunity to alter the open-source code of the GXFS in order to gain a competitive edge. These services are the responsibility of a federation's federator. This is due to the possibility that, depending on the sector, different tools may have different needs. For instance, the requirements of an agriculture or automotive federation may be significantly different according to the functioning of the industry. By creating open-source code, federation participants can create Gaia-X compliant services and freely design the user interface to best suit the federation's purposes (GXFS - eco e.V., 2022).

A repository of the GXFS is kept up to date by the Gaia-X organization. Access is available, and anybody who is interested can develop services using the GXFS open-source code. All participants and interested Gaia-X users can enhance and continually modify the services created under the GXFS umbrella to fit the demands of the Federations through this open-source implementation (GXFS - eco e.V., 2022). As of December 2022, the GXFS Toolbox is divided into five work packages. Several FSs are being developed by the Gaia-X's various teams of industrial partners under each work package.

The next sections provide details on the features and advantages of each FS and explain how Gaia-X users could profit from using them. There are also abbreviations mentioned that are used during the demonstration of usecase integration with GXFS to make it simple and easy to understand.

3.7.1 Identity & Trust (IAT)

Identities are used to access the ecosystem and are dependent on a set of independent qualities and unique identifiers. Gaia-X does not actively preserve identities, it just makes use of them. A specialized identifier format that relies on characteristics of current protocols ensures uniqueness. The identifiers should not contain more information than is necessary because they are similar in their raw form (including personally identifiable information). By cryptographically validating identities using the Gaia-X compliance service, which ensures evidence of identification of the involved participants to ensure that Gaia-X participants are who they claim to be, trust—confidence in the identity and capabilities of participants or resources—is built (GX-TAD-22.10, 2022). Figure 3.9 gives an overview of the federated identity provider and how it is connected with provider and consumer as well as with other FSs (federate catalogue).

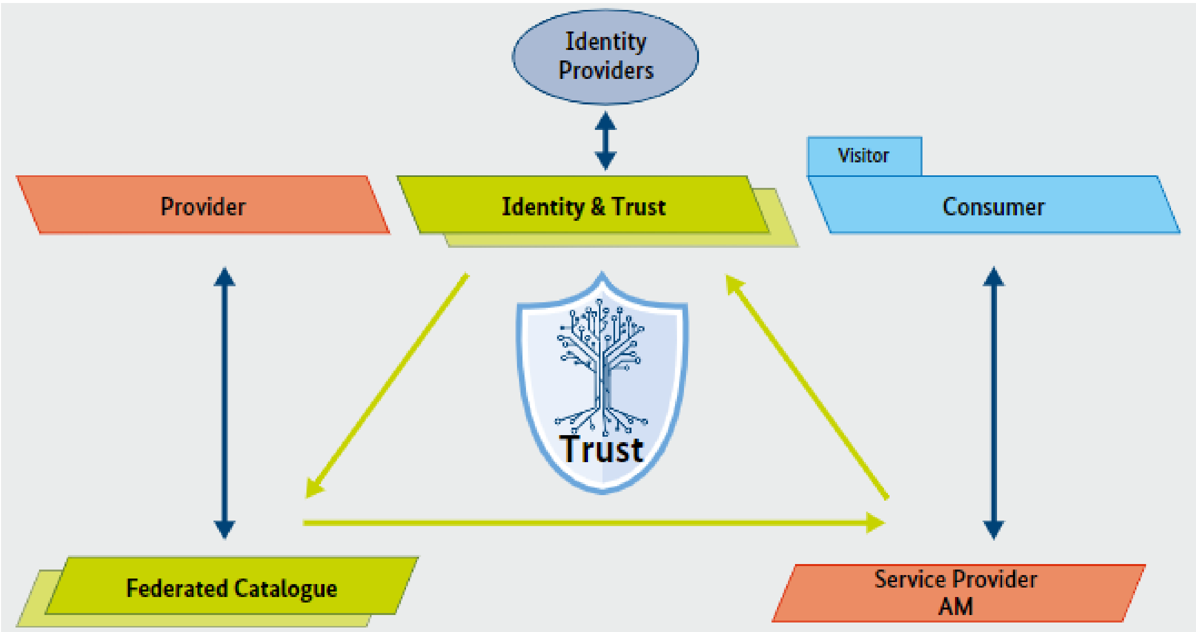

Figure 3.9: Federated identity provider (BMWi PR, 2020)

The FSs under package identity and trust are listed in tabular form. Table 3.2 contains the abbreviation used for the FS, the name of the FS with symbol, and the goal and function of the FS.

Table 3-2: FS Set Identity & Trust

FS	Name	Description
FS01	Authentication and Authorization (AAU) 	• The goal of the service functions to be implemented is to give Gaia-X participants the ability to authenticate users and systems in a reliable and decentralized, self-sovereign manner without the need for a central source of authority. They also aim to ensure that access and data usage based on such identity data and decentralized managed credentials are authorized. (GXFS - eco e.V., 2022). • For authentication and the request of claims, including the proofs that go with them, the service function must provide components that act as a link between SSI-based authentication and the existing OpenID Connect[35] specification. In a similar way, a bridge function to be made available to authenticate system-to-system interactions using the OAuth2 authorization framework[36], dynamic client registration, and the establishment of a reliable mutual TLS-authentication[37] link supported by SSI-based self-sovereign and decentralized authentication and authorization (IDM.AA, 2021).
FS02	Personal Credential Manager (PCM) 	• The goal of the service functions that are to be built is to give Gaia-X users the ability to manage their own credentials. In order to complete the authentication and authorization processes, the user needs secure storage (a user wallet) and presentation capabilities. In support of the decentralized

[35] OpenID Connect: https://openid.net/connect/
[36] OAuth2: https://auth0.com/docs/authenticate/protocols/oauth
[37] TLS: https://curity.io/resources/learn/oauth-client-authentication-mutual-tls/

		architecture, the PCM, a Gaia-X component, is utilized by a private individual. The individual uses the PCM in the appropriate form factor to store the VCs that have been provided to him and to support the claims he has to make in order to acquire a service (IDM.PCM, 2021).
FS03	Organisation Credential Manager (OCM) 	• The goal of the service functions that are to be deployed is to build confidence among the many players in the Gaia-X decentralized ecosystem. All trust-related operations necessary for managing and providing Gaia-X SDs in the W3C VC-format are included in the OCM. Components that, on the one hand, allow for the management of resources and participants for the generation of signatures for a variety of qualities, attributes, and documents and, on the other hand, provide the verification of external documents are necessary in order to accomplish this purpose (IDM.OCM, 2021). • The OCM makes use of other parts, such as GXFS Trust Services, and provides many of the features needed from the GXFS Notarization API part.
FS04	Trust Services API (TSA) 	The goal is to build the necessary confidence within the decentralized ecosystem by centralizing the basic functions and providing standard interfaces used by the other GXFS components. The Trust Services also comprise the tools required to run and manage the developed software components in a corporate context, such as command-line scripts, library functions, API interfaces, etc. The GitOps[38] administration principles are used by the

[38] GitOps: https://about.gitlab.com/topics/gitops/

		policy-driven method to manage the policies. The Trust Services are the central library that composes and coordinates the fundamental cryptographic operations, as well as the policy decision and administration point. (IDM.TSA, 2021).

3.7.2 Sovereign Data Exchange (SDE)

The power to fully control their data interchange and sharing is provided by SDE to participants. Two components of the data ecosystem are included in informational self-determination for all participants: (1) Transparency and (2) Control of data utilization fundamental capabilities and services offered by FS, in conjunction with other processes, ideas, and standards, are necessary to enable data sovereignty when exchanging, sharing, and using data. The Data Sovereignty Services expand on use control theories that go beyond conventional access control. Traditional access control often ignores the data processing perspective in favour of concentrating on the data access dimension. This idea is meant to be broadened, and Gaia-X Data Sovereignty Services aim to close any gaps (GX-TAD-22.10, 2022).

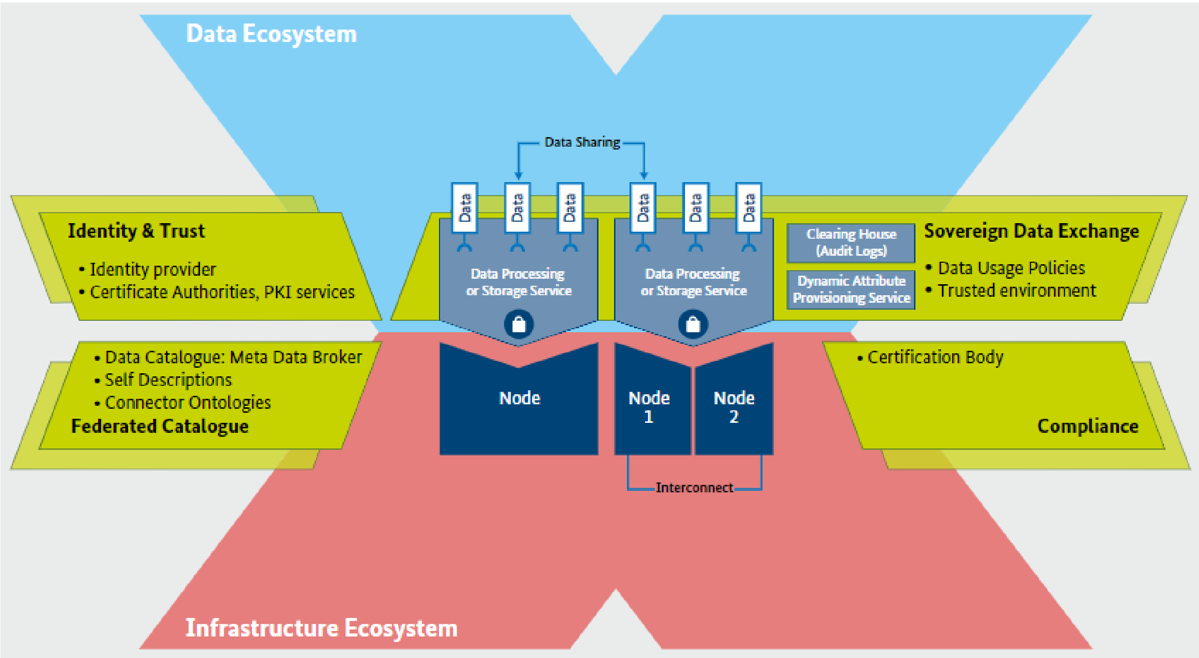

Figure 3.10: Sovereign Data Exchange (BMWi PR, 2020)

Figure 3.10 provides an overview of the SDE and its functioning processes in the data ecosystem. SDE is shown at the top right side of the data ecosystem, as it would operate moreover on the data ecosystem side rather than the infrastructure side.

The FSs under the package for sovereign data exchange are listed in tabular form. Table 3.3 contains the abbreviation used for the FS, the name of the FS with symbol, and the goal and function of the FS.

Table 3-3: FS Set Sovereign Data Exchange

FS	Name	Description
FS05	Data Contract Service (DCS) 	• Within the Gaia-X ecosystem, this service makes it possible for data transactions to take place in a trustworthy, safe, and auditable manner. It provides APIs for negotiating data contracts that define the agreed-upon conditions, such as a data asset usage policy for anticipated data exchange. Data transaction management is not intended for DCS. From a functional standpoint, the DCS offers a formal way for the data supplier and the data consumer to initiate a data transaction. In essence, the service enables the transmission of offers and counteroffers that may either be accepted or rejected (SDE.DCS, 2021). • DCS offers endpoints for starting the handshake and getting the contract for future use. In order to permit metadata logging at the Logging Service, it gives log tokens to the data provider and the data consumer (unless logging is prohibited) (GXFS – eco e.V., 2022).
FS06	Data Exchange Logging Service (DEL) 	• The implementation of the service functions is intended to show that data has been supplied and received and that the Gaia-X ecosystem's rules and duties (data usage policies) have been fol-

		lowed or broken. This aids in both the final clearance of fraudulent transactions and the resolution of operational problems. The data consumer can also monitor and present proof of any violations of data use restrictions (SDE.DEL, 2021). • The DEL offers a useful interface for tracking logging notifications and reading the logging messages afterwards. According to the linked data notifications set out by the W3C, the logging method is provided (GXFS - eco e.V., 2022).

3.7.3 Federated Catalogue (FC)

The FC serves as an index library of Gaia-X SDs to enable the selection of providers and their service offerings. Here, the information provided by participants about themselves and about their services in the form of qualities and claims is known as a SD. Figure 3.11 provides the connection between the provider view and the consumer view of the FC.

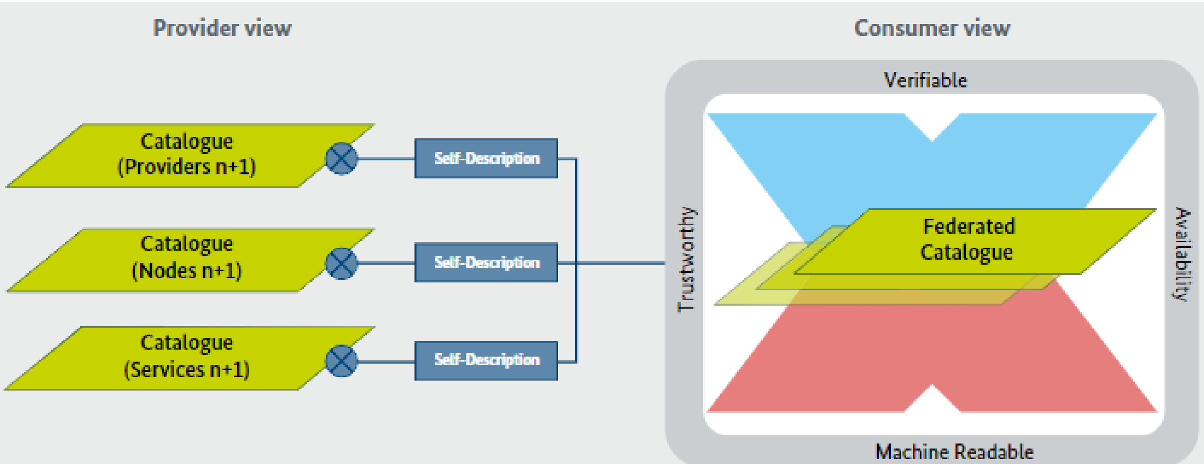

Figure 3.11: Federated Catalogue (BMWi PR, 2020)

The FSs under the package federated catalogue are listed in tabular form. Table 3.4 contains the abbreviation used for the FS, the name of the FS with symbol, and the goal and function of the FS.

Table 3-4: FS Set Federated Catalogue

FS	Name	Description
FS07	Catalogue (CAT) 	• SDs are both individually and collectively stored in a catalogue as a graph data structure. The SD storage contains the raw, issued SD files in the JSON-LD format together with additional lifecycle metadata (GXFS - eco e.V., 2022). • SDs are sent using the JSON-LD format. JSON-LD uses RDF to represent subject-predicate-object triplets, according to the W3C RDF. SD Graph imports the SD from the SD Storage into an aggregate data structure. This serves as the foundation for sophisticated query techniques that take references inside and across SDs into account (FC.CCF, 2021).
FS08	Self-Descriptions Tooling (SDT) 	• The properties of resources, service offerings, and participants that are associated with their respective identifiers are expressed in Gaia-X SDs. The drafting of SD for their resources is the responsibility of the providers. A SD can have self-declared claims made by participants about themselves or the services they offer, as well as credentials that can be checked and were given and signed by reputable parties. Claims about the provider or resources asserted by the issuer are examples of such credentials (GXFS - eco e.V., 2022). • For more information on SDs, See Section 3.5.3.

3.7.4 Compliance

Gaia-X creates a compliance framework using a number of different methods, such as a code of conduct, third-party certifications or attestation, or the acceptance of terms and conditions. The compliance framework consists of requirements that participants must follow, including those for interoperability, data security standards, and encryption.

Gaia-X associations' Data Space Business Committee, Technical Committee, and the Policy Rules Committee are combined to create these guidelines. The key objective of the compliance FS is to give Gaia-X consumers confirmation that each of the individual service offerings adheres to the given guidelines (GXFS - eco e.V., 2022).

The FSs under package compliance are listed in tabular form. Table 3.5 contains the abbreviation used for the FS, the name of the FS with symbol, and the goal and function of the FS.

Table 3-5: FS Set Compliance

FS	Name	Description
FS09	Onboarding and Accreditation Workflow (OAW) 	• The goal of the service functions to be deployed is to ensure that all participants and offerings within the Gaia-X ecosystem are subject to a validation procedure prior to entering the FC (CP.OAW, 2021). • OAW also includes special elements for monitoring compliance relevant basis (such as certificate expiration dates), updating service offering information (the provider is required to submit material changes to the offering for compliance checks), suspending offerings (such as in cases where investigations into potential infractions are ongoing), and revoking offerings (e.g., in the case of proven infractions) (GXFS - eco e.V., 2022). • OAW might be developed such that it may be utilized by various approved stakeholders in various federations. Additionally, it could allow federations

		to modify the "common core" to include, for instance, domain-specific compliance requirements (CP.OAW, 2021).
FS10	Continuous Automated Monitoring (CAM) 	• The implementation of the service functions is intended to give Gaia-X users visibility into the various services offered in the Gaia-X FC and their compliance. The foundation for this compliance offering is a set of specifications and guidelines that Gaia-X has placed on its system, i.e., specifications related to security, including interoperability, data privacy, or encryption (CP.CAM, 2021). • The CAM service collects evidence indicating that those requirements were met by a specific Gaia-X service as a whole or by a specific instance of that service used by a user. This is accomplished by utilizing defined protocols and interfaces to automatically connect with the service under test in order to gather technical data (CP.CAM, 2021).
FS11	Notarisation Service (NOT) 	• The goal of the service functionalities that are to be built is to certify provided master data and change it into a W3C compatible digital representation that uses VCs. To establish the appropriate level of confidence in any offered SD of assets and participants in the decentralized Gaia-X ecosystem, tamper-proof digital assertions about certain features are crucial (GXFS - eco e.V., 2022). • This service has APIs that allow non-IT operators (such as attorneys, notaries, governments, and certifiers) to easily incorporate the notarization component into current applications. The scope also includes the tools required to run and manage the developed software components in an enter-

		prise context, with an emphasis on high availability, security, monitoring, and logging based on industry standards (e.g., command-line scripts, APIs, etc.) (CP.NOTAR, 2021). In order to create an interoperable trust ecosystem, the notarization API makes use of additional components like the GXFS OCM or TSA (CP.NOTAR, 2021).

3.7.5 Portal & Integration (PAI)

A prototype integration layer demonstrating the GXFS and offering convenient access to these services is the Gaia-X portal. It could make it easier for participants to sign up and get approved, put the spotlight on service discovery, and show examples of how to orchestrate and deploy services.

The FSs under package portal and integration are listed in tabular form. Table 3.6 contains the abbreviation used for the FS, the name of the FS with symbol, and the goal and function of the FS.

Table 3-6: FS Set Portal & Integration

FS	Name	Description
FS12	Portal (PRT) 	• The Portal operates as a model for a reference architecture for interacting with core service functions through an easy-to-use UI and associated backend implementation features. The UI offers ways for users to use API calls to communicate with its fundamental features. With a particular focus on identity management, catalogue, security, and compliance across the Gaia-X federated service lifecycles, the objective is to provide a consistent user experience throughout the Gaia-X ecosystem for all actions that may be taken (IAP.PRT, 2021).

		• The portal offers details about Gaia-X assets as well as methods for interacting with them for activities involving their upkeep, including registration process, login process, account/profile details, system information, SD, dashboard etc. (IAP.PRT, 2021).
FS13	Orchestration (ORC) 	• The goal of the service functions that need to be built is to give Gaia-X users the ability to start instantiating and controlling infrastructure services, like virtual machines, through the Gaia-X portal based on the FC search results (IAP.ORC, 2021). • ORC offers an API standard that must be adhered to construct an LCM service. LCM service must be provided by the Gaia-X service providers as a conventional Gaia-X service because it is outside the purview of the FSs. The Gaia-X portal is interfaced with the LCM Engine, which also uses the stated API standard to communicate and coordinate with the LCM services (IAP.ORC, 2021).

4 Context of Project iECO and its Usecases

4.1 Introduction

In the Gaia-X funding competition, the Federal Ministry of Economic Affairs and Climate Action (BMWK)[39] supported exceptionally creative, cost-effective concepts for successful digitalization across a variety of businesses. One idea was developed by RIB Software AG[40] and nine partners.

The consortium's concept sketch for the construction industry is titled "Intelligent Empowerment of the Construction Industry" or iECO[41]. RIB Software AG and the other nine consortium partners have different roles in the project's development based on their expertise in various sectors. Figure 4.1, which gives the schematic view of all partners with their project-specific roles and islands. Gaia-X ecosystem bridges the different islands. Partner islands are termed as different software products the partners already have or would realize over the course of the project, as per the project's requirements.

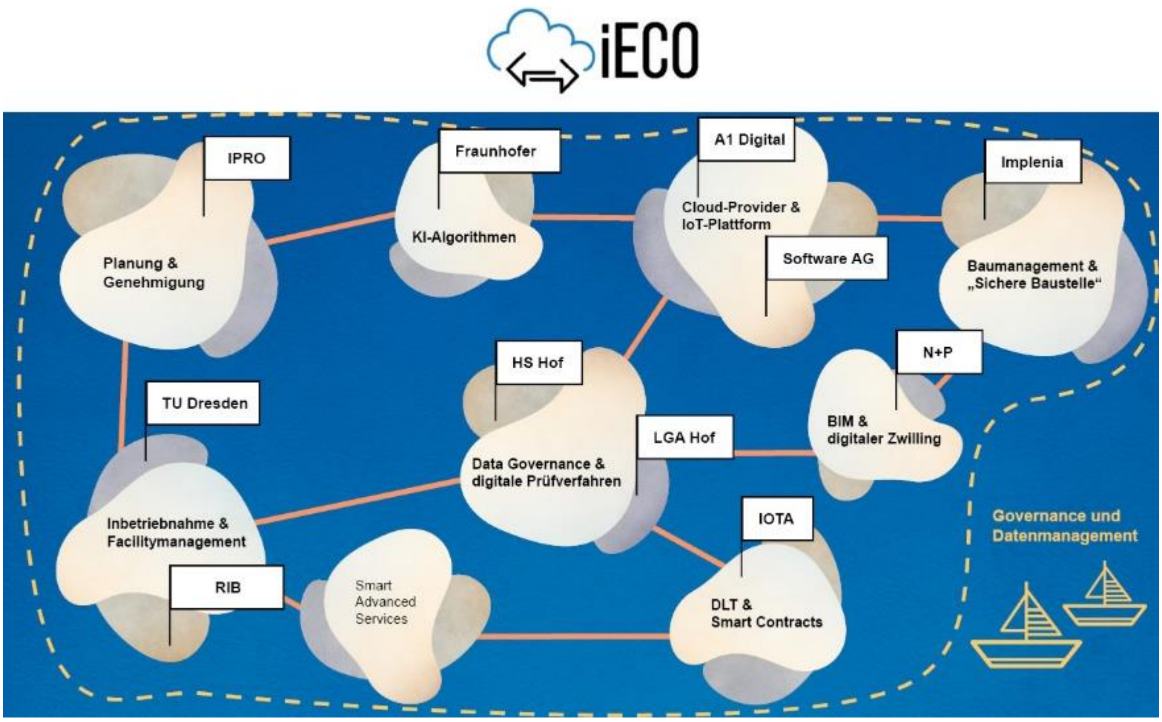

Figure 4.1: Consortium partner islands and roles in project iECO (tech-PR, 2021)

[39] BMWK: https://www.bmwk.de/Navigation/EN/Home/home.html
[40] RIB Software: https://www.rib-software.com/home
[41] Project iECO: https://ieco-gaiax.de/

The Gaia-X ecosystem hosts the information exchange in a shared data room with all participants. The goal of this concept is to eliminate the data silos common to the construction sector and, as a result, make the entire building process smarter (tech-PR, 2021).

4.1.1 Motivation and Aim

Siloed data makes it harder or even impossible for stakeholders in the construction industry to work together effectively. Also, it further increases the already complex collaboration effort in the construction industry, for example, when changes in construction plans or deadlines have to be coordinated manually, and it regularly causes expensive periods of inactivity on construction site (Krauß, 2021). As a result, the construction industry lags behind other industries in productivity by up to 30 percentage points. Project iECO has made it its goal to close this productivity gap and give the construction industry new ways to create value. Project iECO's overall goal is to boost productivity in the construction industry by up to 10 percent. Thanks to the Gaia-X ecosystem, the data providers’ sovereignty over their data is protected, and through Gaia-X it could be possible to share sensitive information with each other and make both the digital twin and SAS possible (BMWK, 2021).

In project iECO, the dataspace is to be used to create a digital twin of the entire life cycle of a building, i.e., from the initial basic assessment to the demolition of the building. Dataspace could also be used to create SASs, which assists in the realization of the digital twin. In flowing sections, the iECO digital twin, iECO dataspace, and SAS are discussed.

4.1.2 iECO - Digital Twin

In order to map the whole life cycle of a construction project, from design and approval through implementation planning, construction supervision, operation, and final dismantling, the data may be utilized, for instance, to generate a digital twin that serves as a "single source of truth". Before implementing plans, extensions, or changes in actual buildings, it is also feasible to do so digitally. On the basis of the collected data, intelligent predictions may also be made. This also saves time and money for projects that would be planned at a later stage, before they are put into practice in actual construction.

An interaction based on contemporary digital artifacts is made possible by a "digital twin," which is a virtual one-to-one representation of its physical twin in terms of semantics, structure, behaviour, and interaction. Like their real twins, digital twins may be set up in hierarchical and heterarchical systems and connected to one another. The Gaia-X ecosystem provides the infrastructure required for the project's digital twin and the iECO data space. This infrastructure also ensures safe data exchange and makes it possible to share data without affecting the exchange medium (RIB iECO, 2022).

4.1.3 iECO - Smart Advanced Services (SAS)

Inspection and approval procedures, for example, can be digitally prepared, construction schedules can be automated or semi-automated, optimized, and adjusted, and construction sites can be monitored in real time using SASs. This not only allows disruptions to be identified and anticipated at an early stage but also increases occupational safety. In addition, project progress, including full or partial acceptance and defect identification or rectification, can be documented transparently and efficiently in smart contracts, or the data created during the planning and construction of a building can be recorded for its subsequent operator. In starting phase of the project iECO, the following SASs are planned (RIB iECO, 2022).

Planning: Data-consistent planning in the shared data space with change management

Building Approval Process: Standardized data repository to speed up review and approval processes (spatial data infrastructure, open data, and environmental monitoring data), as well as regulatory bodies keeping an eye on requirements.

Scheduling and Monitoring of Progress: Construction management aided by AI-based planning and monitoring, optimization, and modification, progress tracking via smart contracts (approval, flaw detection, and correction), as well as inspections during construction.

Work Safety: Enhancing work safety by tracking and monitoring construction vehicles and equipment as well as alerting workers to dangerous locations and/or situations.

Commissioning: Minimizing financial risks during the assurance phase and streamlining the commissioning of buildings and infrastructure. Testing and authorization for use (e.g., fire protection, technical installations), as well as authorization of building work, are required under both public and private legislation.

4.1.4 iECO - Dataspace

A dataspace built on Gaia-X is the backbone of project iECO. The dataspace is used to develop SAS, with these the construction process can be further optimized across the value chain. Project iECO not only involve the construction industry but also the public and other industrial sectors. After all, every construction project should be checked and approved before the construction starts. Therefore, the dataspace helps to create the prerequisites for digital review and approval processes in the construction industry. The secure digital twin eliminates data boundaries in the construction industry (RIB iECO, 2022). The creation of the common data environment (CDE) in project iECO dataspace gives all stakeholders the organizational and technological tools they need to share sensitive information with each other. This makes it easier for everyone to work together along the value chain.
Moreover, the Gaia-X dataspace is discussed in Section 3.2.

4.2 Framework Representation

A framework representation of a project iECO refers to the structure or plan that outlines how the project iECO would be executed and organized. The overall strategy and methodology for executing the project processes would be defined in the framework representation. The framework for project iECO, which would be implemented over the Gaia-X ecosystem, covers the principles, features, and SASs that involved parties would need, to successfully finish the project processes. The iECO framework could offer a standardised and planned strategy to address the issues the construction sector is now experiencing.

With its SASs, Project iECO comprises a variety of usecases, and each usecase process involves various stakeholders working for different objectives. The more services and individuals involved, the more sophisticated it becomes. Furthermore, the implementation of the framework over Gaia-X raises the number of entities in the framework, such as dataspace, GXFS, dataspace connectors[42], etc., making the framework more complex. The usecase processes include the external, non-Gaia-X software because it could be required for a variety of tasks.

[42] Eclipse dataspace connector: https://projects.eclipse.org/projects/technology.edc

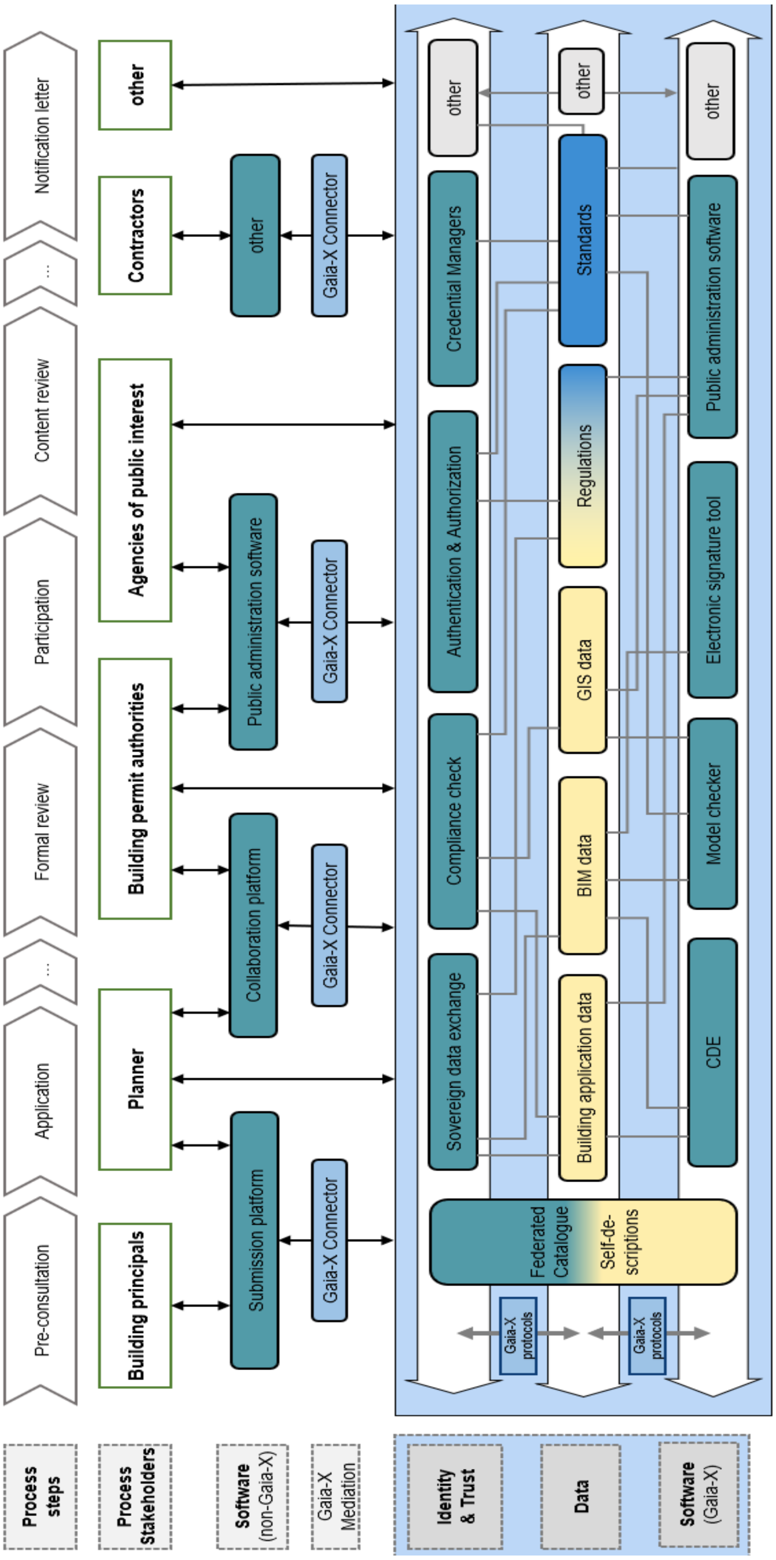

Figure 4.2: Framework Gaia-X-based building permit process (Fauth et al., 2023)

Fauth et al., 2023 has proposed the framework for Gaia-X-based building permit process. One of the six usecases of the project iECO, usecase B, involves the building permit approval procedure in this instance. The schematic of the conceptual framework for the Gaia-X-based process is shown in Figure 4.2. Here, a series of levels are given to delineate the framework. They include non-Gaia-X software, such as different platforms; the Gaia-X connector layer; the data layer, which is the dataspace layer, and all the data to be stored securely in conjunction with Gaia-X compliance and SDs; the GXFS layer that offers services that participants can use; and the Gaia-X software layer, which further involves the Gaia-X functionalities.

4.3 Usecases of Project iECO

There are six usecases for Project iECO, which follow the different stages of construction from environmental planning to building operations. The overview of the usecase processes that result in the creation of the digital twin of the building is illustrated in Figure 4.3. The process begins with UC A and concludes with UC F. Using GXFS functionality, all usecases exchange the data with iECO cloud. iECO cloud is a Gaia-X ecosystem environment where data is exchanged between Gaia-X consumers and other dataspaces. GXFS and the dataspace connector make the connection between two dataspaces secure and trustworthy. Moreover, the iECO framework and example usecase for data utilization are discussed in Chapter 7.

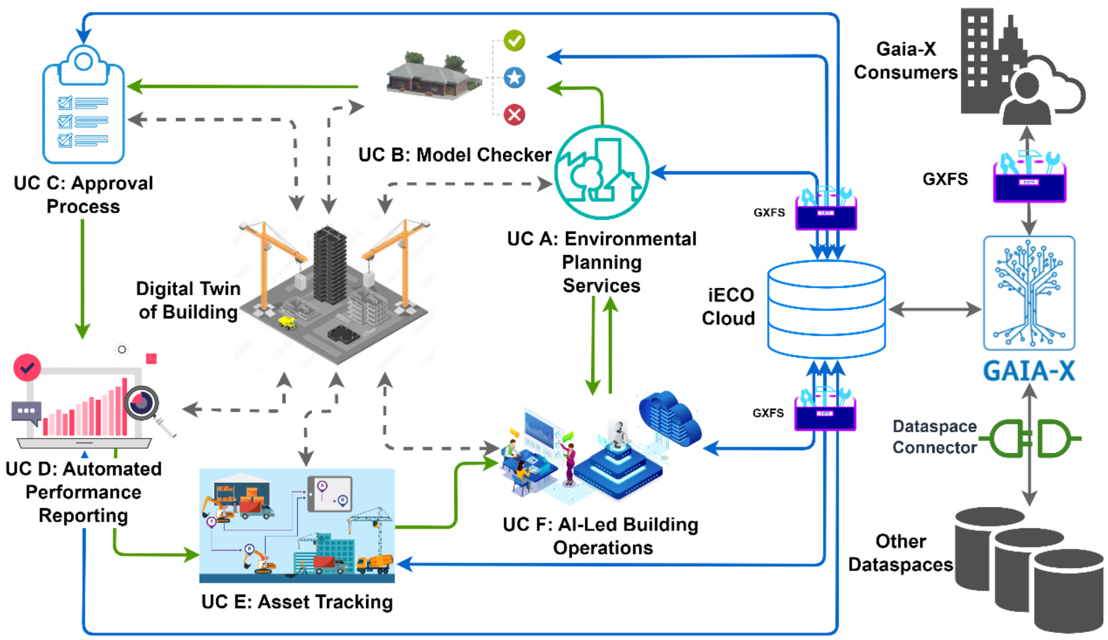

Figure 4.3: iECO usecases and Gaia-X ecosystem

The representative symbols are sourced from draw.io[43] in built libraries and images used in the figure are sourced from the open-source websites[44]. The right side of the

[43] Draw.io: https://app.diagrams.net/

[44] https://stock.adobe.com/es/; https://www.climatechange.vic.gov.au/; https://unocloudtech.com/; https://bowerhousedigital.com.au/

figure illustrates the interactions between the iECO cloud and the Gaia-X ecosystem, as well as those between the Gaia-X ecosystem and other dataspaces and Gaia-X data consumers. Moreover, the possibilities for data consumers addressed in Section 7.3. Here, usecases are discussed briefly to provide a process view and functionalities it contains. The usecase F discussed in detailed form in Chapter 5 and in Chapter 6 the demonstration is provided for the integration with GXFS.

4.3.1 UC A - Environmental Planning Service

Due to climate change, environmental impacts are becoming a greater danger for construction projects. As a result, services based on open geodata and interoperable BIM-GIS systems can aid in complying with the increasingly complicated environmental planning standards, opening the door for the approval of building plans. Additionally, the digital twin contains local site data that was gathered through reports from environmental consultants. From the very beginning, environmental geodata is analyzed along with site and building data. All information pertaining to the environment is given to planners (RIB iECO, 2022).

4.3.2 UC B - Model Checker

The Model Checker offers a standard model-oriented project check within the parameters of applicable standards, legislation, and guidelines for design and approval and transmits the outcomes and reports via the BIM Collaboration Format (BCF). The model check is conducted using a graph database created from the BIM model, which is the key distinction from traditional IFC-based project communication. Additionally, data mining, machine learning, and data-driven design could be done with these databases. The graph database is examined for conformity while relevant technical rules and standards are digitized. A comparable report is sent to the user in the case of any deviations. The use of this service is not dependent on BIM authoring software (RIB iECO, 2022).

4.3.3 UC C - Approval Process

Inspection may now be fully incorporated into the BIM process thanks to a sufficient digitalization of the procedure for the certification of stability. This partnership provides the path for a building to operate sustainably over its full life cycle. The identical specifications that the existing paper process satisfies are met by the new digital method. It is also intended to allow the inspectors the most feasible flexibility for internal procedures (RIB iECO, 2022).

4.3.4 UC D - Automated Performance Reporting

Construction project suppliers can get prompt and clear payment at any time. For outdoor data collection, drones and 360-degree cameras for indoor data collection automatically captures the current situation in real time, which is then analyzed by AI and routinely sent to the digital twin. This finally serves as the foundation for prompt billing following the completion of the service. Any deviations from the original plan are immediately corrected in real time (RIB iECO, 2022).

4.3.5 UC E - Asset Tracking

GPS sensors that track building materials in real time from the manufacturer to the construction site offer assistance in this regard. This allows construction site managers to locate materials at any time, update schedules in the event of late deliveries, and, most importantly, prevent accidents and increase work safety on the construction site. Materials are clearly identified by RFID chips and made accessible through a digital twin. The technology simultaneously keeps track of data related to safety and alerts staff to potentially hazardous circumstances (RIB iECO, 2022).

4.3.6 UC F - AI-led Building Operations

The repository for building certification would be created. In order to make these certificates readily available in the case of a verification requirement, the partners have jointly developed a system that directly interlocks these certificates with the BIM model. The creation of a second repository of standardized procedures for the handover of buildings, systems, subsystems, and components, which includes all commissioning adjustments, are to be completed concurrently. The planners get access to these once they have been gathered through a partially automated method. Finally, a group of partners is working together to create an IT solution to assist operations related to predictive maintenance. Partners would also contribute to developing energy modelling software and a calibration service (RIB iECO, 2022).

5 Usecase F – AI-led Building Operations

5.1 Introduction and Motivation

The coordination of the construction processes on the construction site is very important for the efficient operation of the building. The majority of the projects were delayed due to a lack of coordination. It may also result in delays for the handover and commissioning. Overall, it affects the building residents' experience because the delay in the previous process could also cause the system to run slower. Also, at this stage, a lot of data handover from the contractor to the owner takes place. Before the handover, most of the building-related data would be with the owner, and it must be transferred to the owner at this stage. The contractor generates the documents for approval from the public authority. The documents are then used for the commissioning, and then the operation to be done by the owner through FM services.

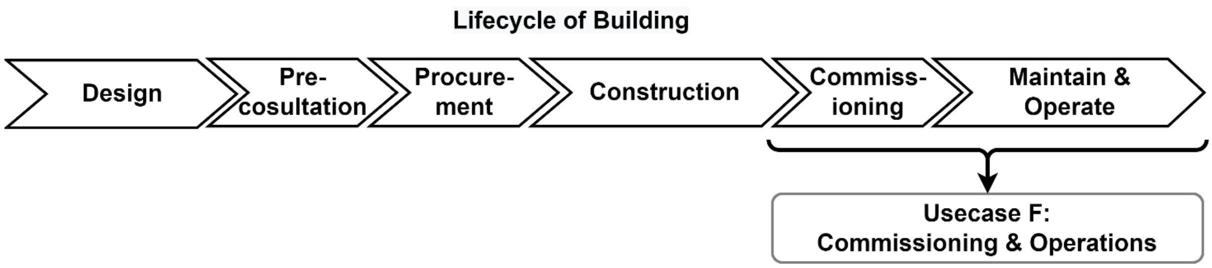

Figure 5.1: Overall lifecycle of building and UC F position

As shown in Figure 5.1, the transition from construction to operation phase changes within the usecase F and comprises three operations: documentation, commissioning, and system operation. Where documentation generation is at the end of the construction phase, commissioning would be done by the public authority after documentation generation is between two phases, and system operations last for a longer period of time throughout the building's lifespan.

Out of the six usecases of the iECO project which are discussed in Section 4.3, the usecase F is selected for the demonstration with GXFS for the thesis work, as the processes involved in this usecase include data generation (documentation) and data transfer from contractor to owner; commissioning of the building by the public authority; and data collection and processing by various FM services (system operations). So these usecase can provide optimal presentation scenario for the thesis work to present with Gaia-X ecosystem and can able to give the described outlook of the idea.

Note: The usecase includes various user terminologies, technical terms, and services provided or used by the participants. They are from the iECO project's usecase partners. Usecase partners have designed the processes in BPMN diagram form for internal use for the project work. Some terms, names, and definitions might differ with real-world project usecases, as they are independently derived and explained for this thesis work by the author. For the sake of simplification and easy data storage representation, the iECO cloud databases are parted out from the iECO cloud and independently named for the thesis work as per its potential use scenario. The usecase processes are termed "AI-led services," as these services uses AI and machine learning algorithms for process automation. But the explanation of the AI services is not explained in detail, as it is out of scope for this thesis work.

In the following chapter, the detailed definition of the usecase processes, explanation of terminologies used in the usecase and sub-usecase processes, and flow of the processes will be explained. Please see the Attachment B.3 for the usecase flow diagrams for visual representation.

5.2 Definition of Usecase

The commissioning and handover of buildings are critical phases in lifecycle-oriented BIM. In these phases, the responsibilities for the BIM change, and on the other hand, new information requirements arise for the operation of buildings. Furthermore, during the commissioning of the systems and facilities, a constant comparison of the digital documentation with the real building must be carried out.

Trust in digital building models can only be established if the condition of the building corresponds to the digital building model on a regular basis. In the field of digital building modeling, the manufacturer-neutral information model of the Industry Foundation Classes (IFC) has become established in practice. Information on the structure and auxiliary structures (the product) as well as the activities to be carried out on the structure (the processes) can be mapped with this model (IDM.TSA, 2021). Figure 5.2 presents the flow of the usecase process. The documentation process leads to the commissioning process in the cloud environment.

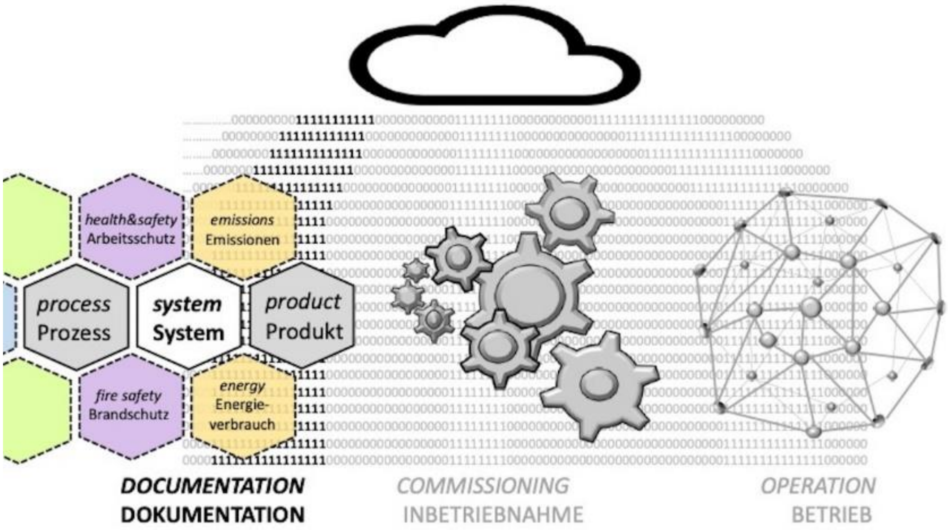

Figure 5.2: Documentation during construction phase (RIB iECO, 2022)

During the commissioning and handover of the buildings, several processes take place that have a major influence on the subsequent safe, complete, and error-free availability of digital models (e.g. BIMs). On the one hand, the execution of the processes depends on the completion of the construction or installation work in accordance with the requirements of the construction project, and on the other hand, it is subject to technical dependencies. For example, without the handover and commissioning of the utilities such as water and electricity, no commissioning of the HVAC systems or the building automation can take place. So these processes are interdependent on each other (RIB iECO, 2022). Figure 5.3 represents the flow of the process from documentation to commissioning and from commissioning to operation over the cloud environment.

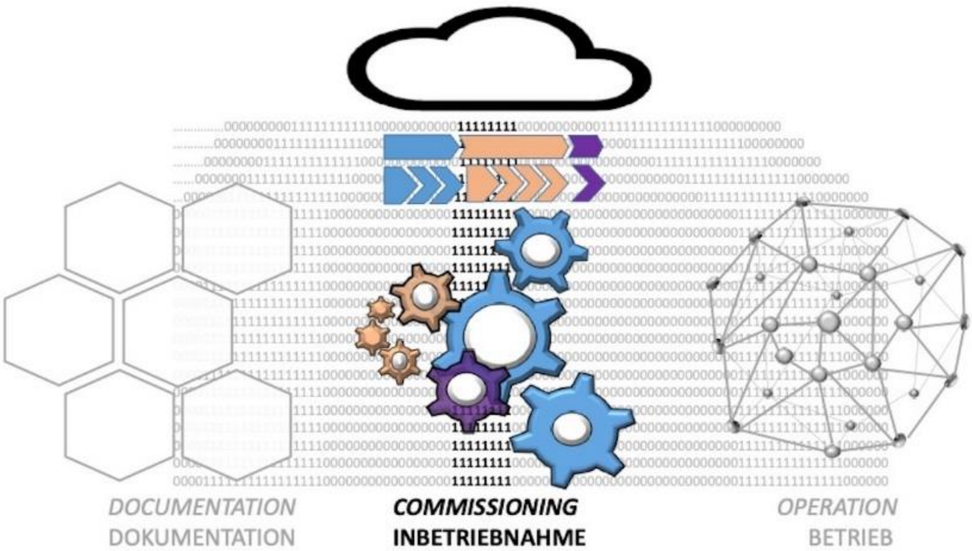

Figure 5.3: Commissioning phase after documentation (RIB iECO, 2022)

The possibilities for collecting and evaluating performance data for the efficient operation of buildings have expanded substantially in the last decade. In many cases, however, this performance data is not evaluated in a structured way and its use often does not go beyond creating opportunities for visual analyses. Another deficit of the solutions currently available on the market for the evaluation of IoT data is the insufficient integration of the applications of monitoring, system simulation, FM (including building automation and maintenance management) and BIM. Thus, the potential of monitoring data in terms of a data economy is insufficiently exploited for the following reasons: (i) due to the lack of use of the possibilities of more precise prediction (predictive maintenance) and (ii) due to the lack of use of IoT data for the calibration of simulation models. Without calibrated simulation models, however, the introduction of performance-based business models becomes possible only to a limited extent. Figure 5.4 represents the operation process.

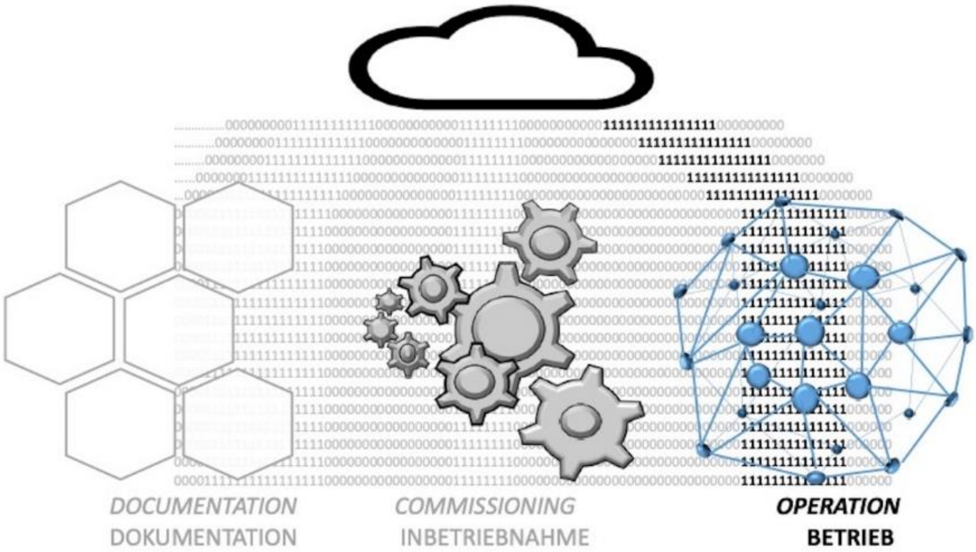

Figure 5.4: Operation phase after commissioning (RIB iECO, 2022)

The AI and its functionalities play very important roles during the usecase processes. The FM uses the AI services to forecast the repairing and maintenance work. Similarly, there are many other services which could be integrated with AI-services to automate the process. The services use the training data as comparison and monitoring data to train the AI-services.

5.3 Terminologies for Participant Roles and Services

In the following tables, the terminologies for various participant roles, usecase services, and iECO database repositories are explained in tabular form.

5.3.1 Participant Roles

Table 5-1: Terminologies for Participation Roles

Role	Description
Owner	Owns the building and appoints the main contractor for the construction work. The owner owns rights to all the physical or virtual data produced by the building before, during, and after the construction work. In the Gaia-X context, the owner owns all rights to the data. The owner deals with the Gaia-X federators for contract-related issues.
Main Engineer	The owner appoints the main engineer for management and looks over the construction work from his side.
Main Contractor	The main contractor manages the overall construction work and operates the sub-contractors.
Sub-contractors	In the usecase there are various sub-contractors involved for various works such as site preparation, civil work, core/shell work, building services systems (electrical, lighting, automation, HVAC, security, and fire systems, etc.), finishing works, etc.
Planer	An architect or architecture firm who plans and designs the building. A planner's role is to integrate various systems involved in building.
Facility Manager (FM)	The FM manages the facilities of the building and appoints service providers for various facility related management tasks. FM would be in major role for system operation after commissioning.
Monitoring Officer	Monitors the facility services.

Service Operator	Operates the facility services.
Facility Services Provider	Provides and maintains facility services.
Public Authority	The public authority is the public body involved in the approval of the plans and building services. It involves various officers from various disciplines for building inspections and provides the approval certificate upon approval.

5.3.2 Services

Table 5-2: Terminologies for Services

Services	**Description**
Compiler for Documents	Compiles the project documents
Entry Assignment Tool	Assigns the entries in logbook and resolves the logging issues. Entries are of acceptance during the construction
Real-time Process Modelling	Generates real-time data of products and process data
FM Services: Various usage as per functioning of services	FM uses the secondary application tools for their need as per the functioning of its services
Management of Activities	Manages the activities of the users
Sub-contractor Services: Electrical & Lighting, Automation, HVAC and Fire Safety - Software and required Tools for Service	Sub-contractors use the secondary application tools as per their particular service needs
Tools for adjustment or change of Parameters	Parameter adjustment and change
Defects Management	Manages deficiencies in process

Update of BIM-Model	Tool to update the BIM-Model with input of the data for BIM-Model
FM Services: Collection, Storage and Analysis Services	Data collection, storage and analysis services
Model Calibration Tool	Calibrates the model for the simulation
Analysis Tool of Status of system and components	Analyses the system and component status
Forecasting Tool for Repairing and Maintenance	AI-powered tool that forecasts the repairing and maintenance work. The training data are provided to train the model for forecasting.

5.3.3 iECO Cloud – Database Repositories:

Table 5-3: Terminologies for iECO Cloud Database Repositories

Database	**Description**
Documentation Database	This database contains all of the project's document-related data. Various processes in the usecase synchronize the document-related data from this database.
Third Party Data Database	This database contains all third-party data. For example, weather data is provided by a third party who is not directly involved in the project. Moreover, it can also store the FS data if required. FS also generated some data while it was running. If Gaia-X and the owner come to an agreement for storing the GXFS data over the iECO cloud repository.
State Comparison Database	This repository contains the training datasets for the state comparison that are needed for the AI algorithms and AI-powered services of the usecase.

Simulation Model Database	The simulation models and calibration models are stored in this data repository.
FM Database	Real-time product and process data are stored in this data repository. The FM services use this database to store their data for maintaining the facility and forecasting the R&M.
BIM-Model Database	This database contained all of the project's BIM-model work.

5.4 Flowchart Representation

The flowchart representation of the usecase processes is attached in Attachment B and Attachment C. Some of the symbols that are commonly used in the diagram and their meanings are discussed here.

For the flowchart representation, the open-source drawing platform draw.io[45] is used. This tool makes it simple and easy to draw processes. Import or export the images, symbols, and other features required for any flowchart diagram.

The symbols used in the diagrams are provided by draw.io and are available as in-built libraries. Common symbols used in the flowchart diagram are listed in tabular form with their name and brief functionality in the context of usecase. In flowchart diagram processes, symbols that are not listed here are written below the symbol.

Table 5-4: Flowchart Diagram Symbol and Lines Representation

Symbol / line	Name	Function / Description
	Synchronization / Data exchange	The processes and services exchange the data with data repositories.
	Data / Data related entity	This symbol is placed at all the data entities and data repositories. The data could be of any type, i.e., documents, IoT data, etc.

[45] Draw.io: https://app.diagrams.net/

	Service	This is the service used by participants. Services have specific features that participants can use for their specific tasks. In the Gaia-X context, services are also provided by external providers.
	Connection line (4 points (pt))	This line shows where the process started or ended.
	Connection line (3pt)	This line shows usecase internal processes.
	Connection line (2pt)	This line shows the data synchronization of usecase services, processes, and database repositories.
	Connection line (2pt, dotted line)	This line shows the participant's interaction with the start and end of processes and services.

5.5 Sub-usecases of Usecase F

5.5.1 UC F.1 AI-led Documentation (See Attachment B.1)

The complete, legally compliant, and efficient handover of certificates of all kinds is an essential part of the handover of building documentation. Many of these certificates are a prerequisite for the commissioning of systems, plants, and the entire building. Certificates are usually requested in legal regulations for the commissioning and approval process of the building. Linking these certificates with the digital building information model (BIM) and the underlying regulations is necessary to get quick and easy access to this information in case of a verification need.

The AI-led documentation process involves three sub-processes, from the generation of documentation for commissioning to operation document generation or renewal at the end of the process.

These processes are explained in detail and divided into sub-processes for simplification, as shown below.

UC F.1.1 Documentation for the Commissioning

This process is initiated by the main contractor. The process begins with the main contractor compiling the subcontractors' documents. He requests the certificates for measurement, certification, finishing works, etc. from various contractors, such as site preparation, core and shell works, building services systems, and finishing work contractors. The certificates from contractors and real time product and process models are being collected and linked with the BIM model of the main contractor. This procedure is carried out via the iECO cloud. The after-compilation documents are synced with the documentation database. Information regarding the update of the documentation for checking the documentation with the BIM model is being shared with the public authority and owner through the main engineer for approval. If not approved, they send a request for the update to the main contractor for further checks. The main contractor repeats the process. If approved, the main contractor changes the status of the BIM model or MMC. It sends confirmation of approval to the BIM-Model for commissioning and assurance. Main contractor ends the documentation process for the commissioning.

UC F.1.2 Approval Procedures on Site

This process is initiated by public authority. At first, conditional entries are being issued and stored in the logbook for pending conditions. Entries without conditions are being resolved until all are addressed. If there are pending conditions, a reminder is being sent to the owner for the solution. At the end, all entries are stored in the logbook. They used the service for the assignment of the entries for approval. The logbook for pending entries is synced with the monitoring data repository. The process is being concluded by public authority.

UC F.1.3 Operation Certification and Renewal

This process is initiated by the FM. FM requests monitoring services, operational services, and documentation updates from the technical service provider and FM-Services. If necessary, they add or update the certificates for measurement and verification protocols, elevators, energy certificates, and so on. The FM updates certificates into the BIM model for commissioning and assurance over the iECO cloud. The BIM-Model is being synced with the Real-Time FM BIM-Model.FM closed the process after updating the database.

Table 5-5: Services involved in Usecase UCF.1

Name	Process involvement
Tool for Compiler for documents	UC F.1.1
Tool for Entry assignment / Checking of entries	UC F.1.2
Tool for Real-time process model	UC F.1.1 / UC F.1.3
Tool for FM Services (Services as software products and tools)	UC F.1.3

Table 5-6: Data generated in Usecase UCF.1

Name	Dataset Type (Examples)	Synchronisation with Data Repository (iECO Cloud)
Certificates	PDF, Document, etc.	Documentation database
Logbook (Pending Conditions)	XLS (spreadsheets), CSV, etc.	Monitoring data repository
Real-Time process model	Process model	State comparison data, Simulation model database, Third party data, FM Database – Real-Time product and processes
BIM-Model (Main Contractor)	BIM, IFC, etc.	BIM data storage
BIM-Model Commissioning and Assurance	BIM, IFC, etc.	BIM data storage

5.5.2 UC F.2 AI-led Commissioning (See Attachment B.2)

The overall planning of commissioning processes is a complex and extremely dynamic process with highly interdependent sub-processes. Another often underestimated aspect during the commissioning phase is the development of knowledge management in the planning offices. In many cases, there is no structured recording of the adjustments and changes made during commissioning, i.e., feedback to the designing engineers is often missing. The AI-led Commissioning process consists of four sub-processes, beginning with commissioning and ending with the acceptance of the BIM-Model.

These processes are explained in detail and divided into sub-processes for simplification, as shown below. In Attachment B.2 the various sub-processes are not drawn separately. As it is one continuous process throughout the entire sub-usecase, the main process start, and end are shown.

UC F.2.1 Commissioning

The main contractor initiates the process of AI-led commissioning with the management of commissioning activities by sub-contractors. He then refers to the commissioning process schedule. Various technical building services system sub-contractors, such as electrical and lighting, building automation, HVAC, security, and fire safety, start commissioning as per their respective work portfolios. The sub-contractors check if the parameters are matching or not. If needed, they change the components.

Planer provides a list of setpoints for commissioning and the simulation model. He uploads the data files to the iECO cloud and to get the design reference values and use them during checking. If there is a change, then it is being updated into the set-point value list and simulation model. The final set-points for commissioning are updated into a list of readjustment control parameters. New components are added to the list of new components when they are added. The lists with added documents from the process accepted by the inspection public authority are further forwarded for the designer's feedback. The process described in UC F.2.1 continues.

UC F.2.2 Feedback to Designer

The lists with added documents from process acceptance by the inspection public authority are further forwarded for the designer's feedback. He gets feedback from the planner for the commissioning process. He forwarded it further. The process described in UC F.2.1 continues.

UC F.2.3 Approval from Public Authority or Engineer

After receiving feedback from designers, BIM-Model is being updated. The sub-contractor during the process described in UC F.2.1, sends the changes to the main contractor. He sends the accepted changes to the inspection engineer or authority. He sends notifications of defects to the defect management service. System approvals are being added to the added documents / MMC. Defect management uses BIM-model commissioning and assurance for improvement and updating. The process described in UC F.2.1 continues.

UC F.2.4 Acceptance of BIM-Model

The BIM-Model real-time FM is updated after the BIM-Model is updated. The FM-BIM model is being sent to the FM Department. For additional FM requirements, the facility service provider accepts BIM for FM. He sends it to the provider and operator of the technical monitoring system to be checked for IoT systems and automation models. If a change to the BIM-model is required, it is sent to the main contractor for approval. The BIM-Model is accepted for further FM and made available to other stockholders.

Table 5-7: Services involved in Usecase UCF.2

Name	Process involvement
Tool for Management of activities (by Main Contractor)	UC F.2.1
Sub-contractor services: Electrical & Lighting, Automation, HVAC and Fire safety (Services as Software and required Tools)	UC F.2.2
Tools for adjustment or change of parameters	UC F.2.3
Defects Management Tool	UC F.2.3
BIM-Model Update Tool	UC F.2.3
FM Services Tool (Services as software products and tools)	UC F.2.4

Table 5-8: Data generated in Usecase UCF.2

Name	Dataset Type	Synchronisation with (iECO Cloud)
Schedule of commissioning process	Document, XLS, etc.	Documentation Database
List of set-point for commissioning	XLS, CSV, etc.	Documentation Database
List of design reference values	XLS, CSV, etc.	Documentation Database
Added-Documents	Documents	Documentation Database
BIM-Model - Commissioning and Assurance	BIM, IFC, etc.	BIM Model Data Storage
BIM-Model - Real-Time FM	BIM, IFC, etc.	FM Database – Real-Time Product and Processes
Simulation Model		Simulation Model Database

5.5.3 UC F.3 AI-led Building Operation (See Attachment B.3)

The usecase UCF.3 involves three sub-processes from sensor data integration to predictive maintenance at the end of the process.

These processes are explained in detail and divided into sub-processes for simplification, as shown below. In Attachment B.3 the various sub-processes are not drawn separately. As it is one continuous process throughout the entire sub-usecase, the main process start, and end are shown.

UC F.3.1 Sensor Data Integration

The FM begins the process of preparing sensor data for integration. The provider of the monitoring system provides data from spatial structures and sensor data from technical systems. Operators provide data from actuators. Facility service providers gather sensor proximity data and building usage data. All of this was saved to the monitoring data repository. UC F.3.1 is still in progress.

UC F.3.2 Condition Analysis through Simulation Comparison

For the calibration of energy simulation, Planer collects data from the monitoring data repository, BIM-Model real-time FM, and weather data from third parties. After the calibration, the energy simulation model is stored in the simulation model database. Planer runs the energy simulation and checks if the optimization is necessary. The data of the energy simulation run is stored as comparison data for AI-training purposes. The condition analysis for the system and its components is being carried out using comparison data and energy simulation data. UC F.3.1 is still in progress.

UC F.3.3 Predictive Maintenance

BIM-Model - Real-Time FM data is used to forecast repair and maintenance work. The training data from the FM operator is used for the process of forecasting the maintenance. Using the forecast, a repair and maintenance plan is being prepared. The plan is shared with the FM operator in order to coordinate building repair and maintenance activities.

Table 5-9: Services involved in usecase UCF.3

Name	Process involvement
FM services: Collection, storage and analysis services (Services as software products and tools)	UC F.3.1
Tool for calibration tool	UC F.3.2
Tool for analysis: Status of system and components	UC F.3.2
Tool for Forecast for repairing and maintenance	UC F.3.3

Table 5-10: Data generated in Usecase UCF.3

Name	Dataset Type	Synchronisation with (iECO Cloud)
Sensor Data, Actuator Data	IoT Data, etc.	Monitoring Data Repository
BIM for Real-Time FM	BIM, IFC, etc.	FM Database – Real-Time Product and Processes
Weather Data (Third Party)		Third Party Database
Simulation Model		Simulation Model Database, State Comparison Database
Repairing and maintenance plan	Document, CSV, etc.	Documentation Database

6 Demonstration of Usecase F with Gaia-X Federation Services

This chapter demonstrates the integration of the usecase with GXFS. The demonstration is done using textual and visual representations of flow diagrams. The chapter is subdivided into five sections. In the first chapter, the diagrammatic representation with graphical symbolism is explained. The demonstration of usecase F processes with GXFS is explained in the second chapter. The flow diagrams are given in the attachment section at the end of the document.

6.1 Diagram Representation

The diagram representation for the demonstration is overall same as that represented in Section 5.3.

The FS symbols are shown near the service or participant symbols to represent that it uses the FS(s) for the particular purposes. At the top of the diagram, over the data repositories and participant symbols, some FSs are shown grouped. It represents that the FSs are used by all the databases or participants below it. This is done to save space on the symbols and avoid a dense representation of the FSs.

6.2 Demonstration with GXFS

The demonstration of usecase processes with GXFS is textually demonstrated in this section. Here the usecase process-to-FS selection-oriented usability representation is chosen to demonstrate the processes. In Section 6.2.1 first usecase process, the technical functionalities are explained in short for every FS. These explanations are avoided in later usecase processes.

Note: It should be noted that the maximum use scenario of the FS capability is demonstrated here. Participants or usecases processes should not be required to use all FSs in their functions. In this demonstration, all FSs are utilized by the usecase participant or services, which are shown textually and graphically in diagrams here so that the reader or software architect can better understand their functionality. It's up to the participant or usecase whether to use the FS functionality or not. However, if FS is used, it makes sure that the specific function is already compatible with the Gaia-X environment. Hence, it could enhance the design and implementation of usecase scenarios for Gaia-X ecosystem integration.

6.2.1 UCF.1 AI-led Documentation (See Attachment C.1)

FS01 Authentication and Authorisation (AAU)

The functionality for authorisation, access management, and authentication, as well as featured applications included with AAU, are used by participants throughout the entire process of this sub-usecase. Participants might use the AAU functionality for functions such as the main contractor authenticating and authorizing subcontractors, the FM authenticating officers and technical service providers, the public authority authenticating officers such as inspection engineers, etc., and the owner authenticating engineers and contractors for the use of Gaia-X functionalities. The authenticator issues credentials through AAU and provides them to their subordinates.

Please see to the left side of the diagram in Attachment C.1 for the visual representation of the processes. The graphical representation of the symbols is provided in the diagram. The FS symbol with a number shows that the participant uses the given particular FS during the usecase process.

FS02 Personal Credential Manager (PCM)

Personal Credential Manager (PCM) is an application running on smartphones and a web-based tool that is used by all the participants in the process. Individuals can save their personal credentials. The project participants and external users can use the functionality of PCM via mobile GUI, web GUI, NFC scanning, QR-Code scanning, and SIOP login.

Every individual participant, from the main contractor to the FM service provider, in the sub-usecase process has one personal credential to participate in the process issued by their co-coordinators (if any). They can use the functionality of PCM to store the personal credentials, which could ease accessibility throughout the project lifecycle.

FS03 Organisational Credential Manager (OCM)

OCM includes the hardware and software interfaces such as connection manager, attestation manager, proof manager, profile manager, etc., which are made available by the Gaia-X Association for the ease of the user.

The coordinators in the sub-usecase process of UCF.1, such as the main contractor, FM, authority, and owner, use the OCM to manage the resources and participants for the generation or usage of the signatures and documents. OCM can also be used for the verification of external documents. In the iECO cloud, data repositories, including third-party databases and documentation databases, use the capabilities of OCM to verify the data to make the data storage, usage, and exchange trustworthy.

FS04 Trust Services API (TSA)

The TSA fosters trust among all service participants and service components. It centralizes the ecosystem by means of decentralization. TSA functionalities such as the policy evaluator, policy management module, task controller, secret store, etc. make the TSA more functional from the participants' perspective. External users, or natural persons, who can create trust between Gaia-X service providers and Gaia-X participants, such as data generators, are able to create a trustful environment to give data for external use outside of the Gaia-X environment.

In the UCF.1 process, all the participants who have credentials from PCM and OCM FS create a trustful environment using TSA. So all participants use TSA to bridge the trust gap during the process. All data repositories in the iECO cloud are anchored with TSA to make them decentralized. TSA functionality is required for trustful data usage environments because the data repository has connections with natural persons or external users.

FS05 Data Contract Services (DCS)

The DCS acts as a broker of data delivery contracts between data providers and data consumers. The data providers or generators are to be the contractors, FM, public authority, owner, and other subordinate participants. External users such as FM companies, insurance companies, building users, and so on are to be data consumers. Every data transaction has the following parts: data assets, SD, publications, search and choice, negotiation and signing, transmission and logging, and billing details.

The main point of access to the data is the iECO cloud, as all the data is being stored and refreshed there. iECO cloud uses the DCS for contracting services between providers and consumers of the generated data. Because there may be an external data transfer during the approval process, the authority also needs to use DCS. DCS contract files can be saved in the iECO cloud documentation database for future reference.

FS06 Data Exchange Logging Service (DEL)

DEL is used in the same way as DCS. However, it might be used after DCS as it logs the transactions in digital formats.

DEL service is in the scope of the iECO cloud as there are transactions for the data between data providers and data users. All the data generated from the usecase processes and services is stored in different iECO cloud databases. The databases are used to sync data between the iECO cloud and services, as well as usecase processes.The database uses DEL to record, log, or access the data. The owner has access to the DEL generated data as it may contain financial transactional data. The authority also uses DEL to log the transactions whenever the data is transferred externally.

FS07 Catalogue (CAT)

The CAT contains two types of storage: one for the published SDs and one for the SD graph. CAT can be accessed by any participant in the Gaia-X ecosystem. For example, a natural person or visitor without a known account can use the CAT using the REST API, and another option to interact with CAT is through the GUI frontend (Gaia-X portal), which is also one FS.

In UCF.1, the participants, services, and iECO databases each have their own SD files, which are generated by the SDT. The SD files are stored in the CAT.

Since CAT needs some storage space to store the SD files, it utilizes the iECO cloud database. The storage might be done over the iECO cloud data repositories, which are to be used with other FS DELS and DCS for the contracting and transactions. The database usage decision could be made by the owner and the federator since it includes the data for Gaia-X functionalities. The CAT data is stored in a third-party database alongside other external data for this usecase process and may also use the API of CAT FS for the storage and management of the SD files.

FS08 Self-Description Tooling (SDT)

SDT can generate the SDs as per the format and requirements set by Gaia-X. SDT makes it simple for users and service providers to create SD quickly and accurately, easing the process of listing the service. Since SDT also has functionality to visualize and validate the generated SD files, it is user-friendly.

In the sub-usecase, all the services listed in Table 5-7 in Section 5.5.1 use SDT. The service provider can use the given API of the SDT for the creation, visualization, and management of the SDs. Each database of the iECO cloud and participants might also use SDT since it is mandatory to have SD to use the Gaia-X portal.

FS09 Onboarding and Accreditation Workflow (OAW)

OAW ensures that the participants and service offerings are compliant with the validation procedure. OAW requires some data storage as it logs the workflow processes with timestamps.

In UC F.1, the participants and service offerings go through the OAW accreditation and onboarding process to ensure that they are compliant with the Gaia-X compliance policy. For the purposes of OAW data storage, it uses a third-party database to store the data. The iECO cloud database repositories ensure the secure storage of the data, and the owner can negotiate using the FS DCS and DELS.

FS10 Continuous Automated Monitoring (CAM)

CAM automatically collects records that demonstrate the compliance or non-compliance of a service as a whole or by a specific instantiation of a service by a user. Dashboards, Gaia-X requirement manager, and evaluation manager are all part of CAM so that the user can easily handle issues related to compliance.

In UCF.1, the service offerings and iECO databases use the CAM as they must be compliant according to the Gaia-X compliance policy. The owner, main contractor, and FM can use CAM to manage compliance issues for all services he uses, whether they are compliant or not as per the compliance policy. CAM functionalities make the compliance process efficient, as it has several in-built tools to manage the various processes.

FS11 Notarisation Service (NOT)

NOT can transform the normal master data into a digitally VC representation. The NOT API seamlessly integrate the notarization component in third-party software for lenders, notaries, governments, and certifiers. NOT includes features such as internal identity management, notarization request management, digital credential issuing, eIDAS compliant signature and document verification tools, and electronic identification tools for the Gaia-X participants. The Gaia-X compliance team can create, together with service providers, the SD and issue it as a digital anchor of trust (CP.NOTAR, 2021).

The owner, main contractor, and authority process UCF.1 using the NOT in usecase to convert data into a digitally VC format that is compatible with Gaia-X. At various stages of the construction process, the owner, main contractor, and authority have to interact with one another for building permission. NOT makes the digital permission process easier because it includes compliance-related tools.

FS12 Portal (PRT)

The PRT contains main functionalities such as searching, exploring, and displaying the content of the Gaia-X federated catalogue. Gaia-X participants can orchestrate services for instantiation through the portal. Portal API has features such as registration processes for organizations and natural persons, login processes, user account UI, etc.

In UCF.1, the data consumer interacts with PRT for the acquisition of the data, data contracting, etc. The iECO cloud contains the various databases where the data are logged by the usecase processes, participants, and services. A visitor or participant in the usecase process can go to the Gaia-X PRT for login and have a look at the service SD of databases as per their requirements. For example, FM firms or third parties could be the sole users of the portal and acquire data through the Gaia-X PRT.

FS13 Orchestration (ORC)

ORC helps the Gaia-X PRT by providing the LCM engine for the management of the services. LCM Engine API, PPR API, and LCM Services API are all part of the ORC API.

In UCF.1, ORC is utilized mainly by the PRT and the services offered. PRT uses the different APIs to manage the service providers, deployed services, and database-related services and helps the participants do LCM analysis of their services or the services they are using.

6.2.2 UCF.2 AI-led Commissioning (See Attachment C.2)

FS01 Authentication and Authorisation (AAU)

Participants in this usecase process, such as the main contractor, authority, owner, and FM, use AAU to authenticate their particular subordinates. The authenticator issues credentials through AAU and provides them to their subordinates.

FS02 Personal Credential Manager (PCM)

Every individual participant in UCF.2 can use PCM to store their personal credentials. They can utilize the smart functionality of PCM for access and logging on the Gaia-X portal dashboard.

FS03 Organisational Credential Manager (OCM)

In UCF.2, the participants who have the role of authenticator uses the OCM to manage the credentials and documents issued. OCM users and AAU participants are the same, as they use AAU functionality for credential issuing. Similar to the UCF.1, iECO cloud data repositories, such as third-party databases and documentation databases, might use the OCM to verify the data usage and data exchange during the sub-process.

FS04 Trust Services API (TSA)

Similar to the UCF.1 process, all the participants who have credentials from PCM and OCM could be able to build trust using TSA. So, all participants will use TSA to bridge the trust gap during the process. All of the data repositories in the iECO cloud could be anchored with TSA to make them decentralized and to create an environment where external users and participants involved in sub-usecase process can trust each other.

FS05 Data Contract Services (DCS)

In UCF.2, the processes stores the data in the iECO cloud data repositories, and data exchange is to be processed through the Gaia-X portal. As a result, data repositories use DCS functionality to facilitate contracting between data providers and consumers.

The contracting data are saved on the iECO cloud repository after an agreement with the owner.

FS06 Data Exchange Logging Service (DEL)

After the data is contracted through DCS, the data usage and other data related details might be logged through DEL. Data storage or exchange between the iECO cloud repository and data from the sub-usecase processes is to be logged through DEL. The owner has access to DEL-generated data as it contains the contracting and data logging details. The DEL log-files are stored in a data repository after an agreement with the owner.

FS07 Catalogue (CAT)

The participants, services, and iECO cloud data repositories have their own SD files, which are generated by the SDT. These files are stored in the CAT.

The CAT data is stored on the iECO cloud database. The database usage decision could be made by the owner and the federator since it includes the data generated by Gaia-X FS functionality. The CAT data, along with other external data for this usecase process, are stored in a third-party database.

FS08 Self-Description Tooling (SDT)

The services listed in Table 5.9 of Section 5.5.2 use SDT to generate their specific service SDs and files. Services offered by subcontractors and FM can use the services offered by other providers on Gaia-X for their specific needs. All the participants and the iECO cloud data repository need to have SD to participate in Gaia-X processes. The SDT API also helps manage SD-related settings.

FS09 Onboarding and Accreditation Workflow (OAW)

In UCF2, the participants and service offerings go through the OAW accreditation and onboarding process to ensure that they are compliant with the Gaia-X compliance policy. For the purposes of OAW data storage, it uses a third-party database to store the data. The iECO cloud database makes sure that the data is stored safely, and the owner can use the FS DCS and DELS to negotiate.

FS10 Continuous Automated Monitoring (CAM)

In UCF.2, the service offerings and iECO databases use the CAM as they must be compliant according to the Gaia-X compliance policy. The owner, main contractor, and FM can use CAM to manage compliance issues for all services they or other subordinates use, whether they are compliant or not, as per the Gaia-X compliance policy. CAM functionalities make the compliance process efficient, as it has several in-built tools to manage the various processes.

FS11 Notarisation Service (NOT)

In UCF.2, NOT used by the owner, main contractor, and authority to transform data into Gaia-X compliant digitally VC format. At various stages of the construction process, the owner, main contractor, and authority have to interact with one another for building permission. NOT makes the digital permission process easier because it includes compliance-related tools.

FS12 Portal (PRT)

In UCF.2, the data consumer interacts with PRT for the acquisition of the data, data contracting, etc. The iECO cloud databases contain the various databases where the data are logged by the usecase processes, participants, and services. A visitor or participant in the usecase process can go to the Gaia-X PRT for login and have a look at the service SD of databases as per their requirements. For example, FM service provider or third parties could be the sole users of the portal and acquire data through the Gaia-X PRT.

FS13 Orchestration

In UCF.2, ORC is to be utilized mainly by the PRT and the services offered. PRT uses the different APIs to manage the service providers, deployed services, and database-related services and helps the participants do LCM analysis of their services or the services they are using.

6.2.3 UCF.3 AI-led System Operations (See Attachment C.3)

FS01 Authentication and Authorisation (AAU)

Participants in this sub-usecase process, FM and authorities, use AAU to authenticate their particular subordinates. Planer authenticated by the owner for its participation in this usecase process. The authenticator issues credentials through AAU and provides them to their subordinates.

FS02 Personal Credential Manager (PCM)

Every individual participant in UCF.3 can use PCM to store their personal credentials. They can utilize the smart advanced functionality of PCM for access and logging on the Gaia-X portal dashboard.

FS03 Organisational Credential Manager (OCM)

In UCF.2, the participants, such as the FM and authority, who have the role of authenticator, use OCM to manage the credentials and documents issued. Participants in OCM and AAU are the same because they both use AAU functionality to issue credentials. Similar to the UCF.1, iECO cloud databases, such as third-party databases and documentation databases, use the OCM to verify the data usage and data exchange during the sub-process.

FS04 Trust Services API (TSA)

Similar to the UCF.1 process, all the participants who have credentials from PCM, OCM are able to build trust using TSA. So, all participants use TSA to bridge the trust gap during the process. In the iECO cloud, all the data repositories are anchored with TSA to enable decentralized and trustful data exchange between participants in the sub-usecase process and external users, or data consumers.

FS05 Data Contract Services (DCS)

The UCF.3 sub-usecase processes stores the data in the iECO cloud repositories, and data exchange is processed through the Gaia-X portal. As a result, data repositories use DCS functionality to facilitate contracting between data providers and consumers. Following an agreement with the owner, the contracting data to be saved on the iECO cloud repository.

FS06 Data Exchange Logging Service (DEL)

After the data is contracted through DCS, the data usage and other data related details are logged through DEL. Data storage or exchange between the iECO cloud repository and data from the sub-usecase processes is logged through DEL. Though the owner is not involved in the process, he has access to the DEL-generated data as it contains the contracting and data logging details. The DEL log files are to be stored in a data repository after the agreement with the owner.

FS07 Catalogue (CAT)

Similar to UCF.1 and UCF.2, the participants, services, and iECO databases each have their own SD files, which are generated by the SDT. These files stored in the CAT.

The CAT data might be stored on the iECO cloud database. The database usage decision could be made by the owner and the federator since it includes the data generated by Gaia-X FS functionality. The CAT symbol is displayed in third-party databases because the data is generated by CAT FS rather than by usecases.

FS08 Self-Description Tooling (SDT)

The services listed in Table 5-11 in Section 5.5.3 use SDT to generate their specific service SDs and files. The FM service provider can use the services offered on the portal, so they also need their specific SD to use the services. All the participants and the iECO cloud data repository need SD to participate in Gaia-X processes. The SDT API also helps manage SD-related settings.

FS09 Onboarding and Accreditation Workflow (OAW)

In UCF3, the participants and service offerings go through the OAW accreditation and onboarding process to ensure that they are compliant with the Gaia-X compliance policy. Onboarding of the services is to be done through the service provider. For example, if FM service providers offer services, they ensure onboarding using OAW. For the purposes of OAW data storage, it uses a third-party database to store the data. The iECO cloud database ensures the secure storage of the data, and the owner can negotiate using the FS DCS and DELS.

FS10 Continuous Automated Monitoring (CAM)

In UCF.3, the service offerings and iECO databases use the CAM as they must be compliant according to the Gaia-X compliance policy. The owner and FM may use CAM to manage compliance issues for all services he or other subordinates use, whether they are compliant or not as per the compliance policy. CAM functionalities make the compliance process efficient, as it has several in-built tools to manage the various processes.

FS11 Notarisation Service (NOT)

The owner and authority in UCF.3 use NOT to transform data into Gaia-X compliant digital VC format. At various stages of the construction process, the owner, builder, and authority have to interact with one another for building permission. NOT make the digital permission process easier because it includes compliance-related tools.

FS12 Portal (PRT)

In the usecase UCF.3, the data consumer interacts with PRT for the acquisition of the data, data contracting, etc. The iECO cloud contains the various databases where the data are logged by the usecase processes, participants, and services. A visitor or participant in the usecase process can go to the Gaia-X PRT for login and have a look at the service SD of databases as per their requirements. For example, an FM service provider or third parties could be the sole users of the portal and acquire data through the Gaia-X PRT.

FS13 Orchestration

In UCF.3, ORC is utilized mainly by the PRT and the services offered. PRT uses the different APIs to manage the service providers, deployed services, and database-related services, and helps the participants to do LCM analyses of their services or the services they are using.

7 Results and Discussion

Following the demonstration of Project iECO's usecase, a discussion of the overall context and the challenges posed by the Gaia-X ecosystem is required. In this chapter, the usecase framework is discussed as a result of the demonstration with one consumer-oriented example of the data utilization through Gaia-X. The challenges that the construction industry may face in implementing Gaia-X are also discussed.

7.1 Added value of Gaia-X ecosystem in iECO Context

The goals and guiding principles of the Gaia-X-based iECO platform are secure and long-lasting peer-to-peer data transfer between businesses and organizations in the construction industry. The purpose of the usecases developed for the iECO project is to illustrate the enormous potential that Gaia-X presents for the construction sector. This specifically involves the reliable and scalable exchange of information across corporate borders and the distribution of data to various players (Kraemer, Prosotowitz, et al., 2022). With their unique portfolios for data generation, utilisation, and interchange, several players in building operations and construction sites contribute to a single objective. The iECO cloud's data repositories is the where created data is stored, as was mentioned in Section 5.3.3, the usecase processes log and save the data into these repositories. Participants in the processes use the services during the usecase operations to function. The Gaia-X portal might be used to access the services in the Gaia-X ecosystem. Participants support the operation of their workplaces and diversify their portfolios in accordance with how the services are used.

7.2 Usecase Framework

The Plan-Build-Operate integrate lifecycle and usage phase involve frequent data interchange between the physical and digital twins, which are connected to one another. AI, machine learning, sensors, and IoT technologies enable real-time data interchange and dynamic data collection (buildingSMART, 2020). Here, the digital twin created through Gaia-X-based iECO dataspace allows the stakeholders to work together in a decentralized and sovereign way.

The architecture of the iECO usecases is summarized in Figure 7.1. Usecase F is illustrated here for overview purposes; however, this approach might be used to explain all other usecases. Data sharing between data providers and consumers is made feasible by the functionalities of the Gaia-X data ecosystem, such as GXFS. Project stakeholders that give data to customers are considered “Providers” in the iECO dataspace. “Service Providers” that supply the services. The “Dataspace Connectors” are used by the providers and their services to interact with the Gaia-X ecosystem securely. Inter-organizational and sovereign data communication is enabled through connectors like the eclipse dataspace connector. The services provided by “Federators” are included in the GXFS toolbox, which streamlines the participation procedures. These FSs make it simple to interact with the Gaia-X ecosystem, as already explained during the usecase demonstration in Chapter 6. “Consumers” are Gaia-X's natural participants who search the data as per their needs. “FM“ is another data consumer who needs data for system functionality.

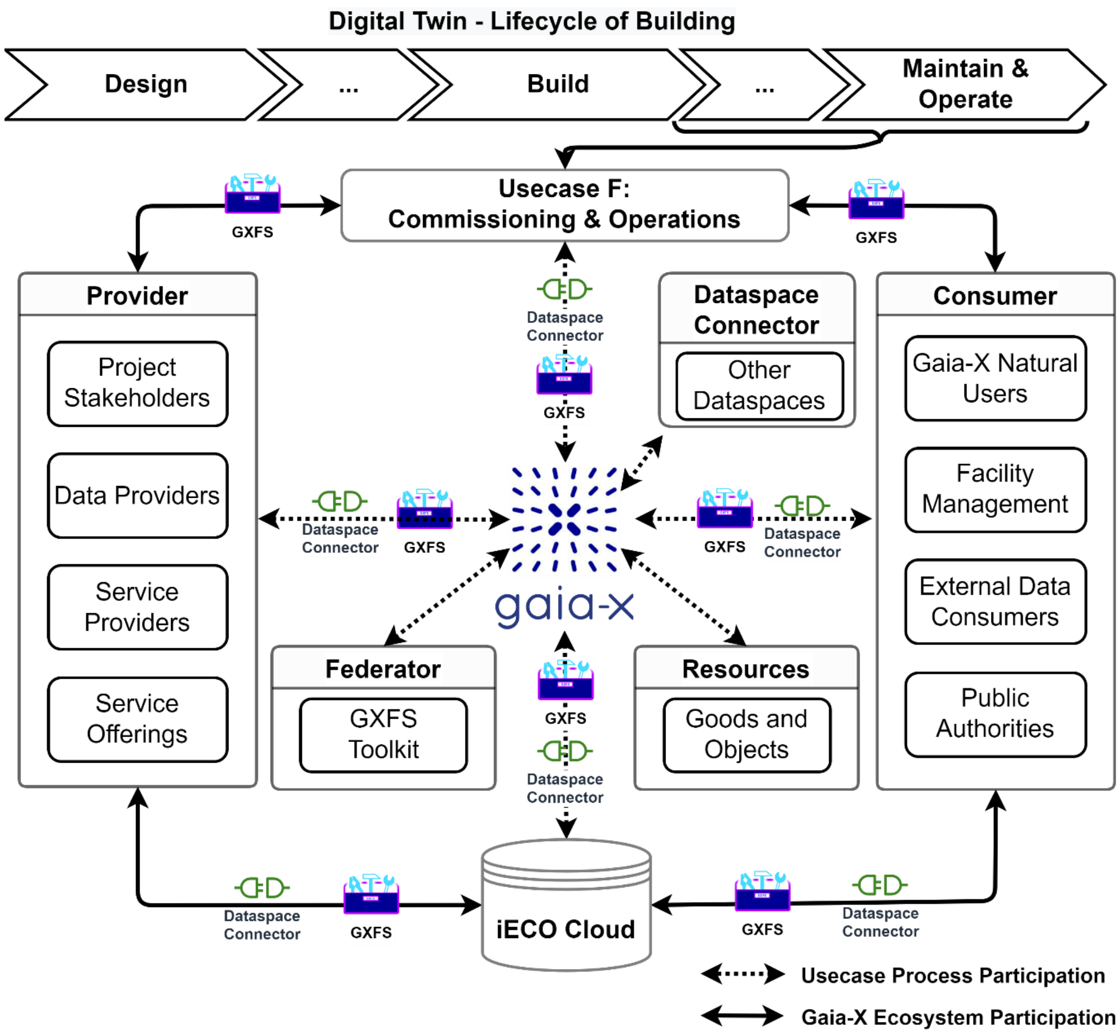

Figure 7.1: Gaia-X-based framework of usecase F

The data is used by “Public authorities”, including municipal organizations, government agencies, and others, for a variety of objectives. In a similar manner, it is connected via the dataspace connector and utilizes the GXFS Toolkit. Since they engage in the processes at different levels and use the GXFS for various purposes, providers and consumers could also be able to connect directly to the usecase processes. All of the usecase processes involved are covered in Section 5.5. The dataspace connector and GXFS toolkit are used by the iECO cloud, which contains a variety of repositories, to participate in the Gaia-X ecosystem. Also, using the dataspace connector and GXFS tools, providers and customers connect and log their data into the iECO cloud.

7.3 Consumer-oriented Decentralised Gaia-X Approach

A schematic representation of the decentralized Gaia-X-based framework's consumer-oriented approach is shown in Figure 7.2. Here, the consumer is the FM department, which requires building data for a number of activities and analyses. In addition to utilizing the iECO cloud data, FM also stores the data in the iECO cloud during the usecase process. FM acquires the monitoring data during system operations. GXFS is to be used to acquire and contract for this data. As mentioned in Section 6.2's demonstration section, it employs a variety of FSs, including DCS, DELS, and others.

FM participates in the usecase procedures for numerous operations. When the facility is operational and data is required, FM typically manages the various building operations for FM. The “iECO Portal” in this instance functions as a dashboard for controlling and accessing the services and data of all processes. FM uses GXFS when interacting with the iECO portal. FM gathers IoT data throughout the operation and employs actuators for actuation actions. In addition, the collected monitoring data and AI technologies are used to perform predictive maintenance in order to anticipate repair and maintenance work.FM uses the BIM model for real-time FM, which was generated over the course of the process and contains various process data.

The data is logged into the Gaia-X dataspace from the iECO cloud by the iECO dataspace, which uses the dataspace connector for the data exchange with other Gaia-X dataspaces. The Gaia-X environment makes alternative dataspaces and external Gaia-X data consumers possible. The decentralized Gaia-X architecture for data sharing allows for the exchange of data with other dataspaces.

This is an example of how the consumer's approach may seem when FM is operating the building. The Gaia-X ecosystem and GXFS enable sovereign participation in the ecosystem from all other players, including providers, consumers, and federators.

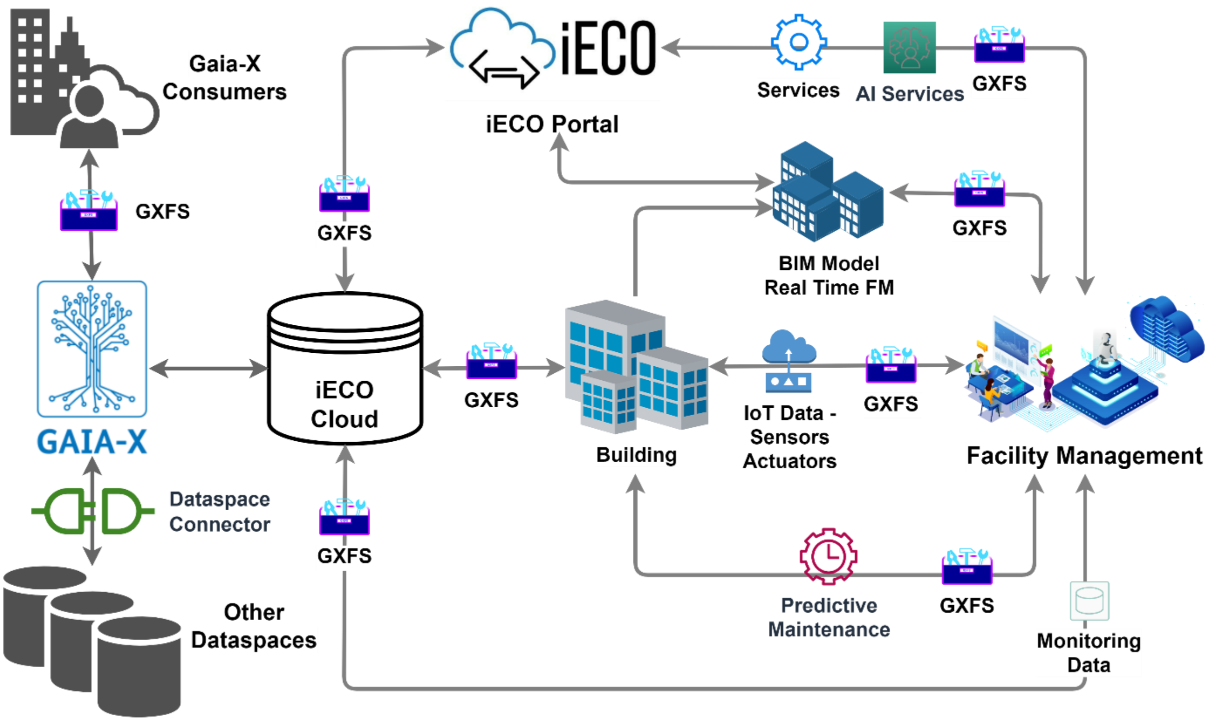

Figure 7.2: Consumer-oriented decentralized Gaia-X approach

7.4 Interoperability with other Gaia-X Dataspaces

Similar to how project iECO progresses, many other industries are also cooperating on Gaia-X ecosystem to create SASs for different sectors. The idea of a data space emphasises the importance of data being kept locally rather than centrally. The only time semantic interoperability is used to transmit them, when it is essential. The only people who maintain data in the Gaia-X dataspaces environment are the Gaia-X association's members. Several dataspaces, including industry 4.0/SMEs, health, education and skills, energy, mobility, finance and insurance, and space dataspace, are already in use. Specific data are offered by each dataspace. In doing so, it creates a stable foundation for one or many ecosystems. Cloud/Edge infrastructures host the software necessary to implement data spaces (Gaia-X.DS, 2023).

In regard to data spaces and data sharing within Gaia-X dataspace communities (See Figure 7.3), one example of a data ecosystem might be explored. From planning to operation, the building-related data would be stored in the iECO dataspace. Data on insurance-related matters might be found in Gaia-X's finance and insurance dataspace. The service provider and customer are both present in the iECO dataspace. The insurance provider wants some information before settling on an insurance policy for a building when one of the building's tenants wants to get insurance for their flat. Therefore, the insurance provider may now access the Gaia-X portal and obtain the data there as needed. The Gaia-X ecosystem takes care of all data compliance and privacy-related matters. Insurance companies can thus provide policy premiums based on the history of the buildings after analyzing the data they have collected. Gaia-X dataspace interoperability and data interchange might open up new usecase possibilities that are potentially feasible. The names given to the other Gaia-X dataspaces are imaginary and used for simplicity in the example.

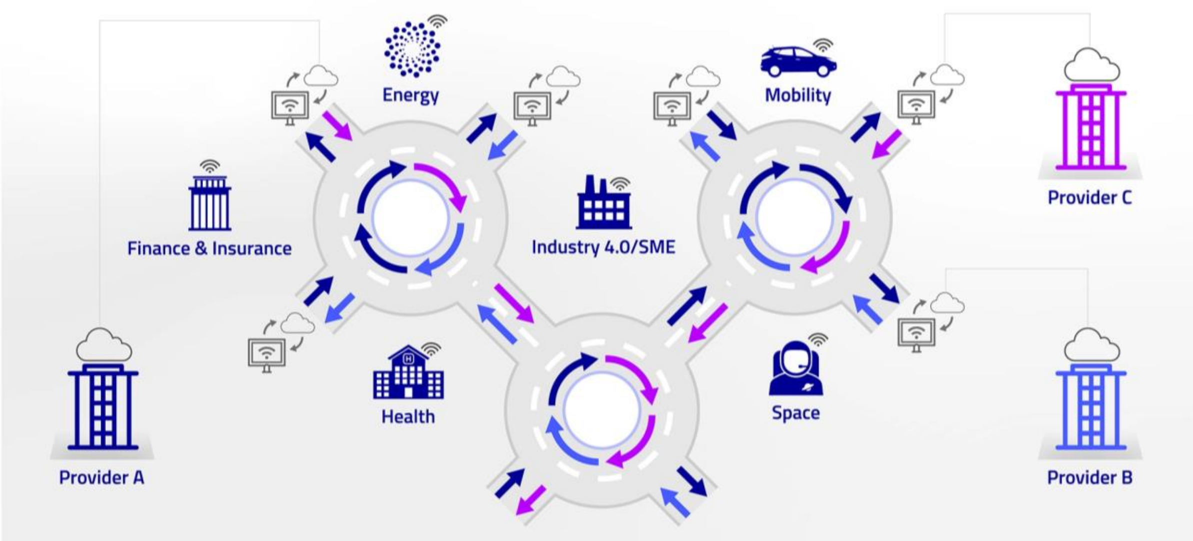

Figure 7.3: Gaia-X dataspace community (Gaia-X.DS, 2023)

7.5 Challenges of Gaia-X Implementation in Construction Industry

Gaia-X Technical Challenges

In a general context, the Gaia-X ecosystem's technical challenge is to make sure that various systems and technologies can coexist. For data exchange, this entails creating uniform standards and protocols and ensuring system and technology compatibility (Tardieu, 2022). For scalability, it is necessary to construct scalable technological infrastructure, including data centers, networks, and storage systems. It also calls for the use of cutting-edge data management strategies, including data analytics and data warehousing (Malicki, 2022). In regard to the technical infrastructure, Gaia-X has a major task in establishing the technical framework that facilitates data exchange. This entails both the development of technological solutions, such as data analytics and data warehousing, to assist data management and analysis as well as the selection and deployment of hardware and software components, such as data centers, networks, and storage systems (GX-TAD-22.10, 2022).

Gaia-X ecosystem implementation in the construction industry might face challenges such as fragmented and diverse data formats, the need for interoperability between various software systems, the privacy of sensitive documents from cybersecurity threats, and the establishment of adequate infrastructure for data gathering, backup, and analysis in extreme circumstances. To overcome these hurdles and capitalize on the potential given by the effort, standardization, collaboration, and the development of new skills and capabilities should be required.

Gaia-X Economical Challenges

Among all the economic challenges, the competition in this field is already enormous. Gaia-X ecosystem is up against established international cloud service providers like Amazon, Microsoft, and Google. These businesses have a big consumer base and a big head start. In terms of cost, building and maintaining a cloud infrastructure on the scale required for Gaia-X is an expensive and difficult task. It necessitates a large investment in infrastructure, resources, and technology for the development of the Gaia-X ecosystem (BMWi-19.10, 2019).

The construction sector is extremely competitive, and the Gaia-X ecosystem must demonstrate a clear return on investment in order to justify the cost of implementing new procedures and systems. To take advantage of the opportunities in the Gaia-X ecosystem, companies might need to develop new business models and funding sources that adapt to the new data-driven economy. Traditional industrial business strategies might not be adequate to fully comprehend the advantages of Gaia-X.

Gaia-X Organisational Challenges

The organizational challenges that Gaia-X is facing or may face in coming times are mainly in the field of regulations and governance, as it has to comply with the GDPR of the EU. Gaia-X ecosystem must adhere to a number of rules and guidelines according to the local country in the EU as well, which might make things more complicated and slow down the implementation process (Ladid et al., 2021). For Gaia-X to succeed, a clear governance framework must be established. Roles and duties, decision-making procedures, and dispute resolution procedures must all be defined (Tardieu et al., 2022).

In context of the organizational challenges for implementation of Gaia-X in the construction sector, these involve collaborations, data governance, competencies, and learning problems. To enable open and ethical use of construction data, including ownership and access rights, clear data governance frameworks are required. Cooperation is essential for innovation and competitiveness, but the industry's heterogeneity makes collaboration difficult. To take advantage of the Gaia-X initiative prospects, the sector must create new skills and competencies in areas such as data analytics, organization, and data security.

The European economy and companies stand to gain significantly from Gaia-X, but it also confronts substantial organizational and economic hurdles that must be overcome if it is to be effective. In conclusion, to tackle challenges posed by the Gaia-X ecosystem, a comprehensive approach comprising the construction industry, technology providers, and lawmakers might be needed. Stakeholders should collaborate in order to create a safe, extensible, and transparent data environment that could promote innovation and competition in the construction sector.

8 Conclusion and Outlook

8.1 Conclusion

With this thesis, it could be concluded that the potential benefits of the Gaia-X ecosystem and its adjoining services like GXFS can have real-world potential to leverage the value of the data generated by entities. In the construction sector, an entity could be a building or any infrastructure project. The project participants might be able to make processes more digitalized and efficient in terms of time delays and economic perspective by utilizing the project iECO's SASs. Digitalization in the construction industry and domain change are also promoted through Gaia-X ecosystem. Gaia-X ecosystem’s outcomes assist several companies in the construction industry by networking and fostering innovation and cross-sector collaboration.

The Gaia-X ecosystem has various advantages for the building sector. Gaia-X ecosystem seeks to standardize data formats, protocols, and APIs to enable smooth data integration and communication across various stakeholders in building projects. This could facilitate better data integration, reduce data silos, and reduce manual processes. Project iECO’s usecases also reduce manual processes, which might aid the sustainability of the construction project.

AI-led applications might benefit from having the training data accessible to train the AI-datasets for various specialized tasks, as Gaia-X encourages innovation by making data ecosystems and infrastructure available. Some SASs in Project iECO are AI-driven; therefore, they require monitoring data and historical data for a variety of activities. Any authorized Gaia-X ecosystem participant or member, who requires the data in accordance with the criteria is permitted to join the ecosystem, obtain the data, and utilize it in a sovereignly compliant manner to meet their specific needs.

The Gaia-X ecosystem places a significant focus on data privacy and security, which is crucial for the construction sector because it has to preserve sensitive information like building plans, contracts, and financial data. Through the framework presented for the project iECO usecase and GXFS, data sovereignty is enhanced by the Gaia-X ecosystem, which gives data owners or building owners control over how and where their data is kept and processed. The construction sector, where sensitive financial data is frequently involved in projects, may find this to be of particular importance. By offering a decentralized but centralized platform for data management, the Gaia-X ecosystem, with its services such as GXFS, enables construction companies to access and manage data from many sources more easily. Better data management and integration could allow the construction sector to make better decisions based on accurate and current data, thereby also aiding in sustainability goals.

8.2 Outlook

The research on building data collection, storage, and utilization was studied throughout the thesis, but there are very few studies available that scientifically derive the clear methods used in the construction industry. As the Gaia-X ecosystem is still in its early stages of development, there is limited scientific research available. Integration of the framework with the ecosystem is not always the same as it depends on the requirements and usecase processes. The limited research on the Gaia-X ecosystem has potential to study it scientifically and leverage the benefits from it for various sectors.

The approach outlined in the thesis might facilitate future projects in the building industry and other commercial sectors by integrating their services or usecases on Gaia-X sovereign data infrastructure. The approach proposed for integrating GXFS with usecases may assist software developers in developing and designing software that is compliant with and interactable with the Gaia-X ecosystem. Non-Gaia-X users might find the simplified overview of the Gaia-X ecosystem helpful in swiftly grasping its concepts. The GXFS functions that are presently being created or are in the early stages of development may be able to assist the software architect in connecting their unique functionalities with the GXFS toolkit functionalities, speeding up integration. It might be easier for readers to understand how GXFS is used in the overall usecase procedures if a demonstration using textual and graphical flowchart representation is provided.

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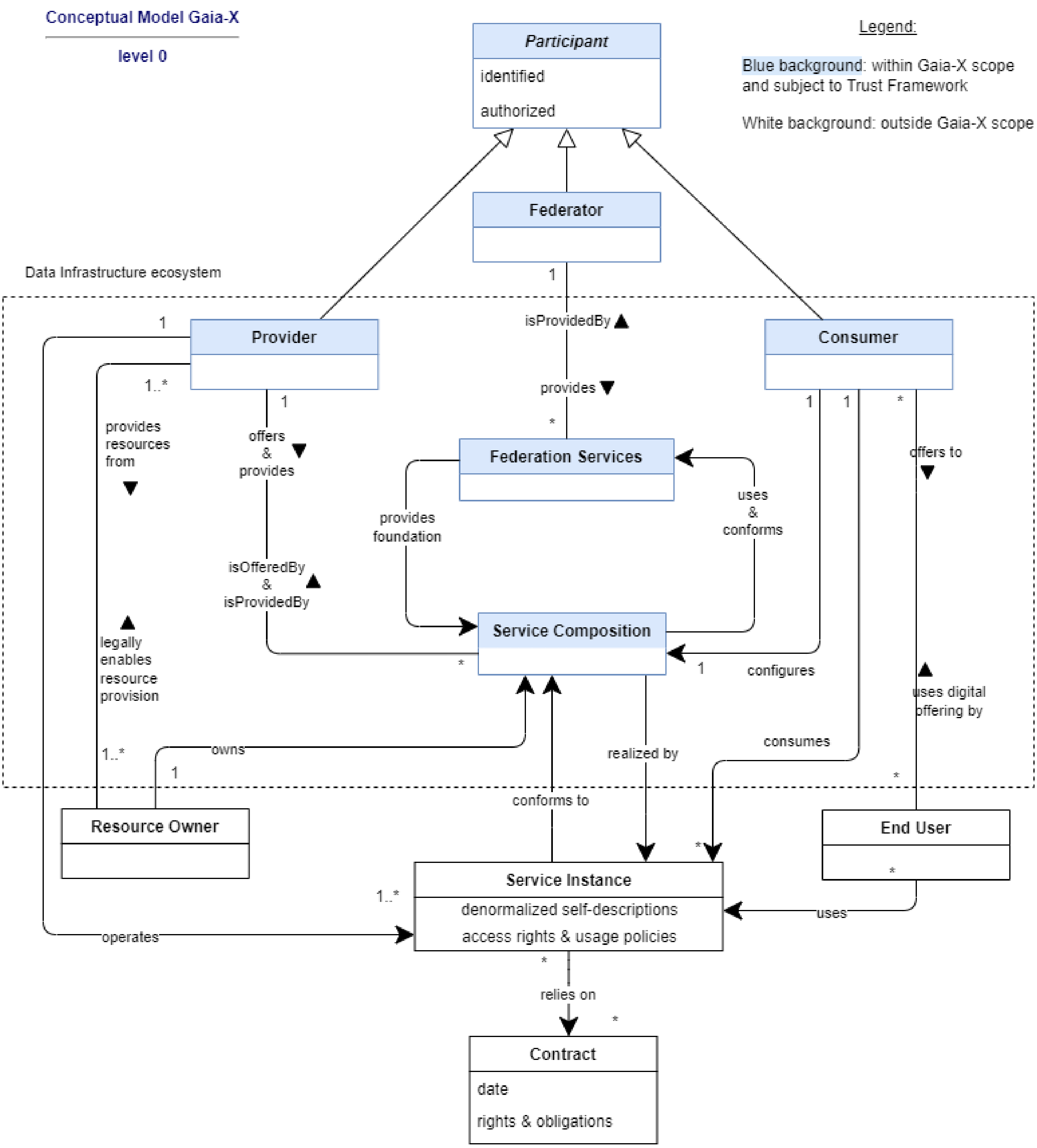
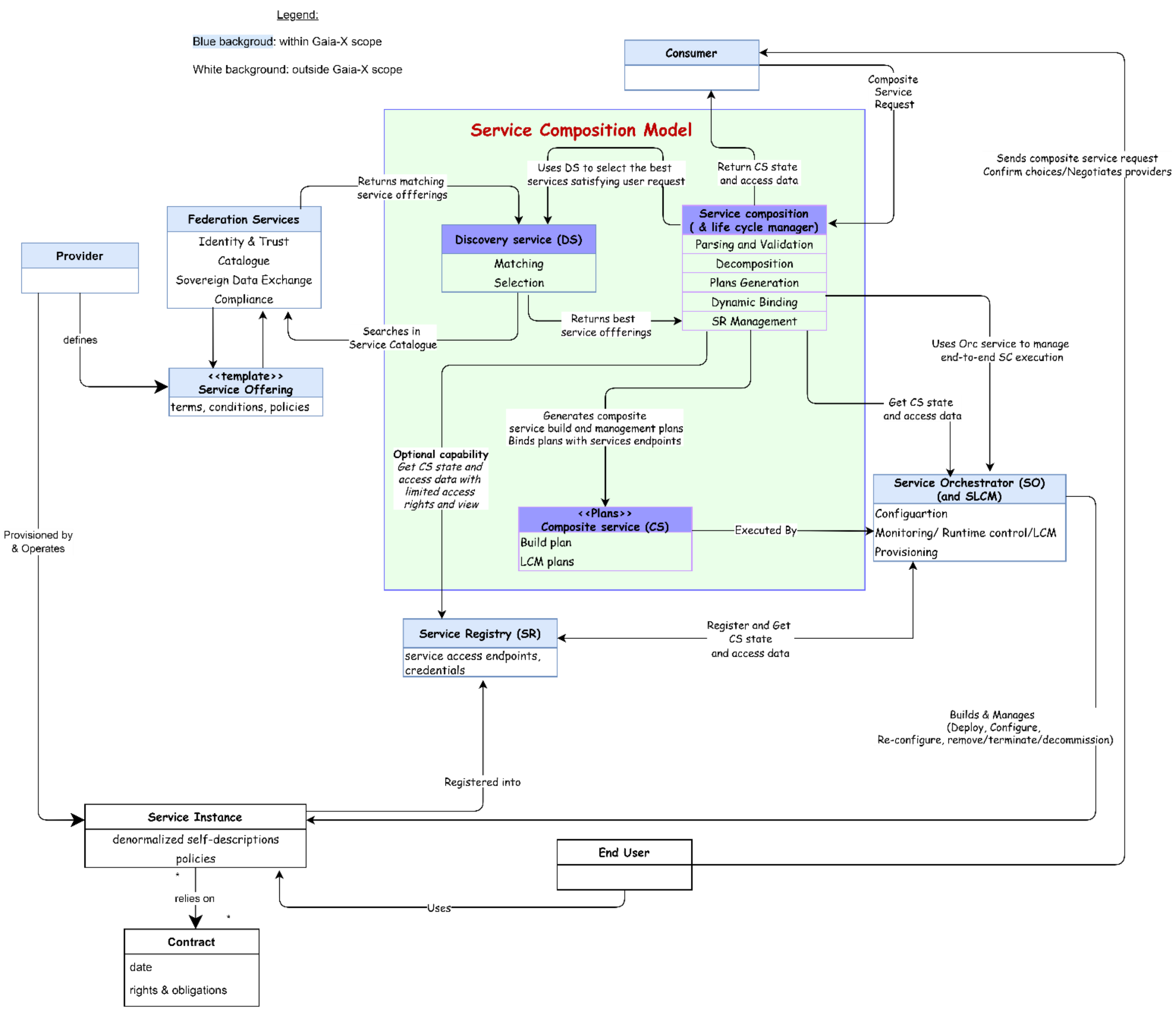
Attachment A

Attachment A.1: Gaia-X Conceptual Model (GX-TAD-22.04, 2022)

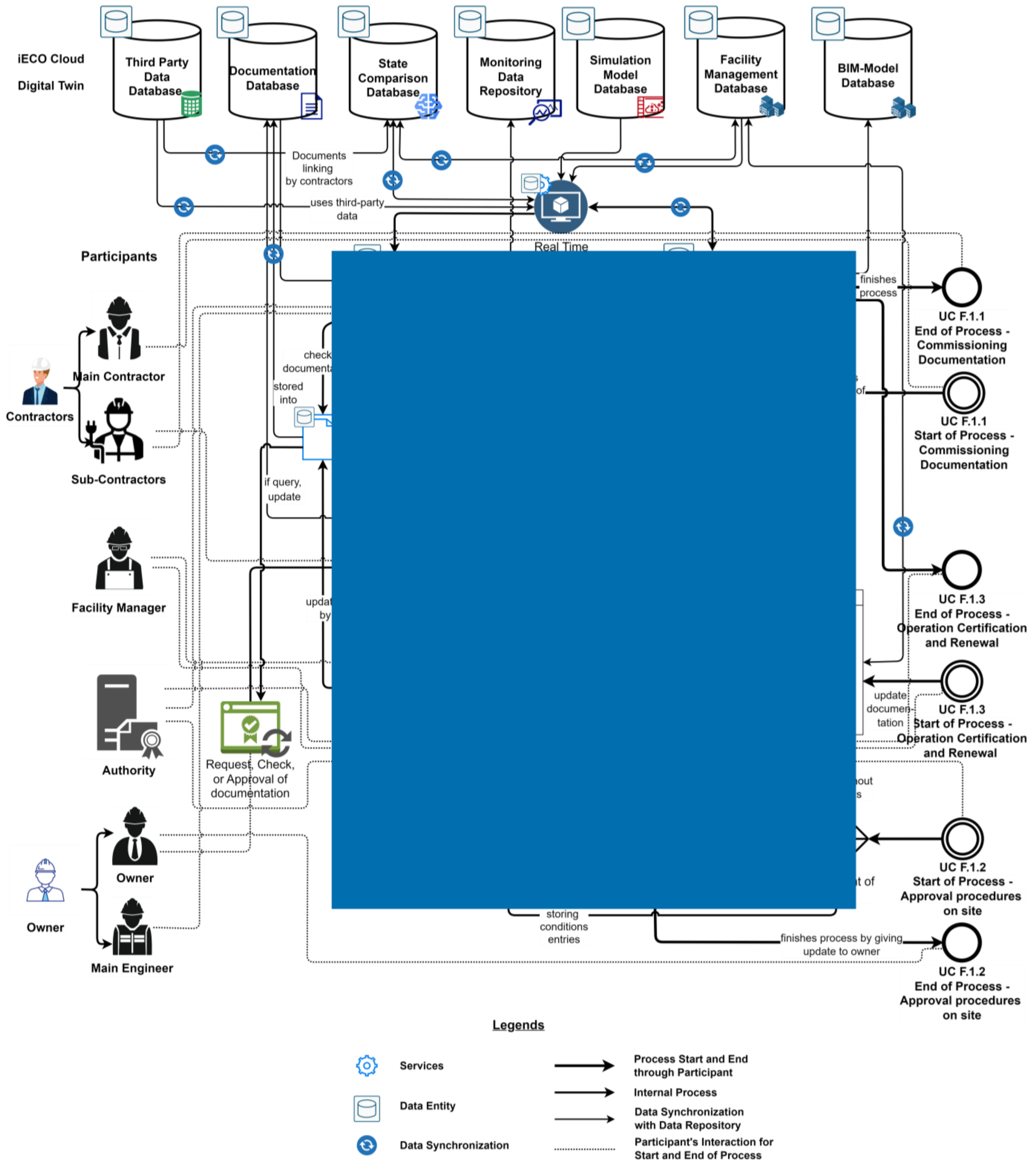


Attachment A.2: Service Composition Model (GX-TAD-22.10, 2022)

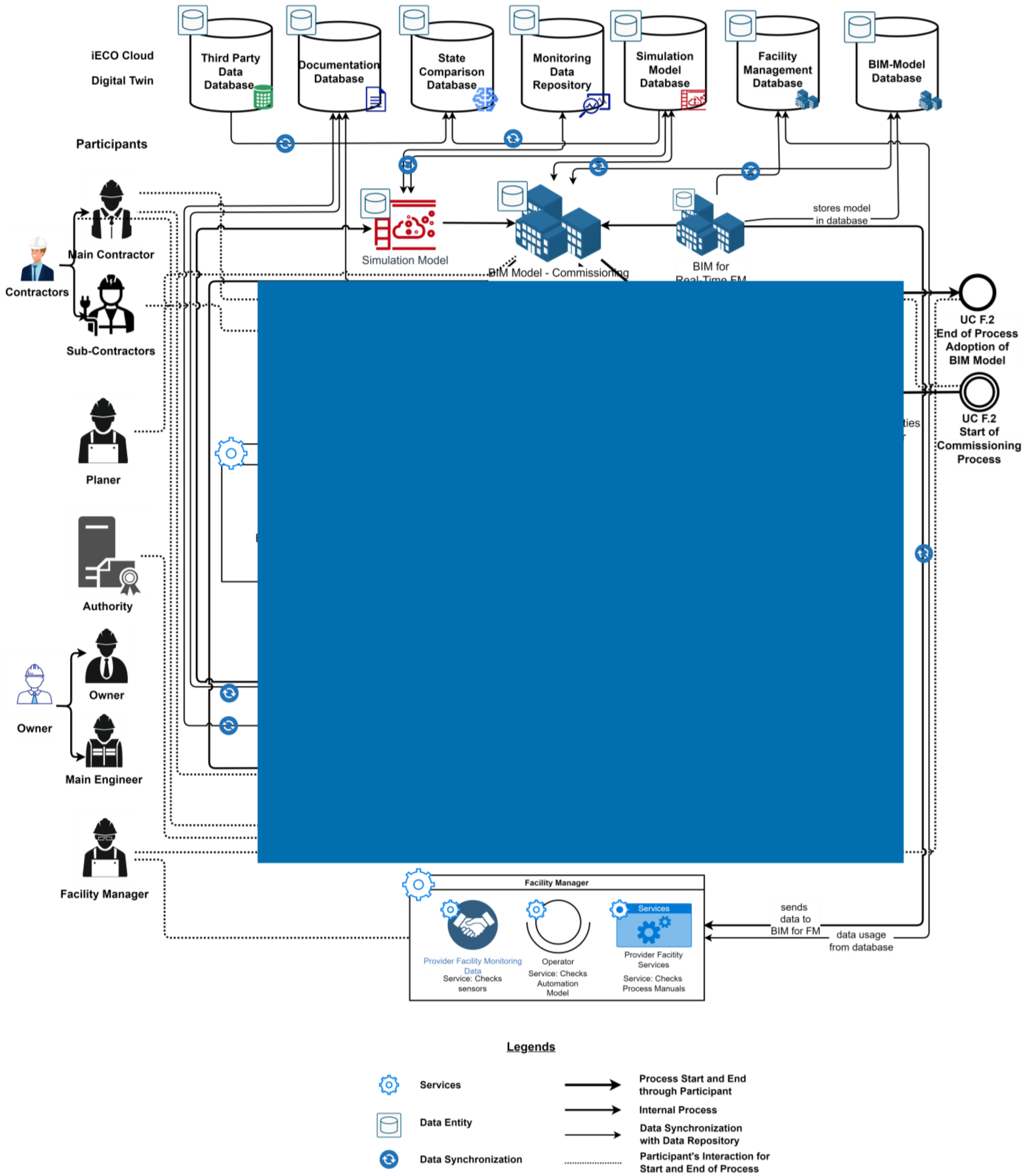


Attachment B

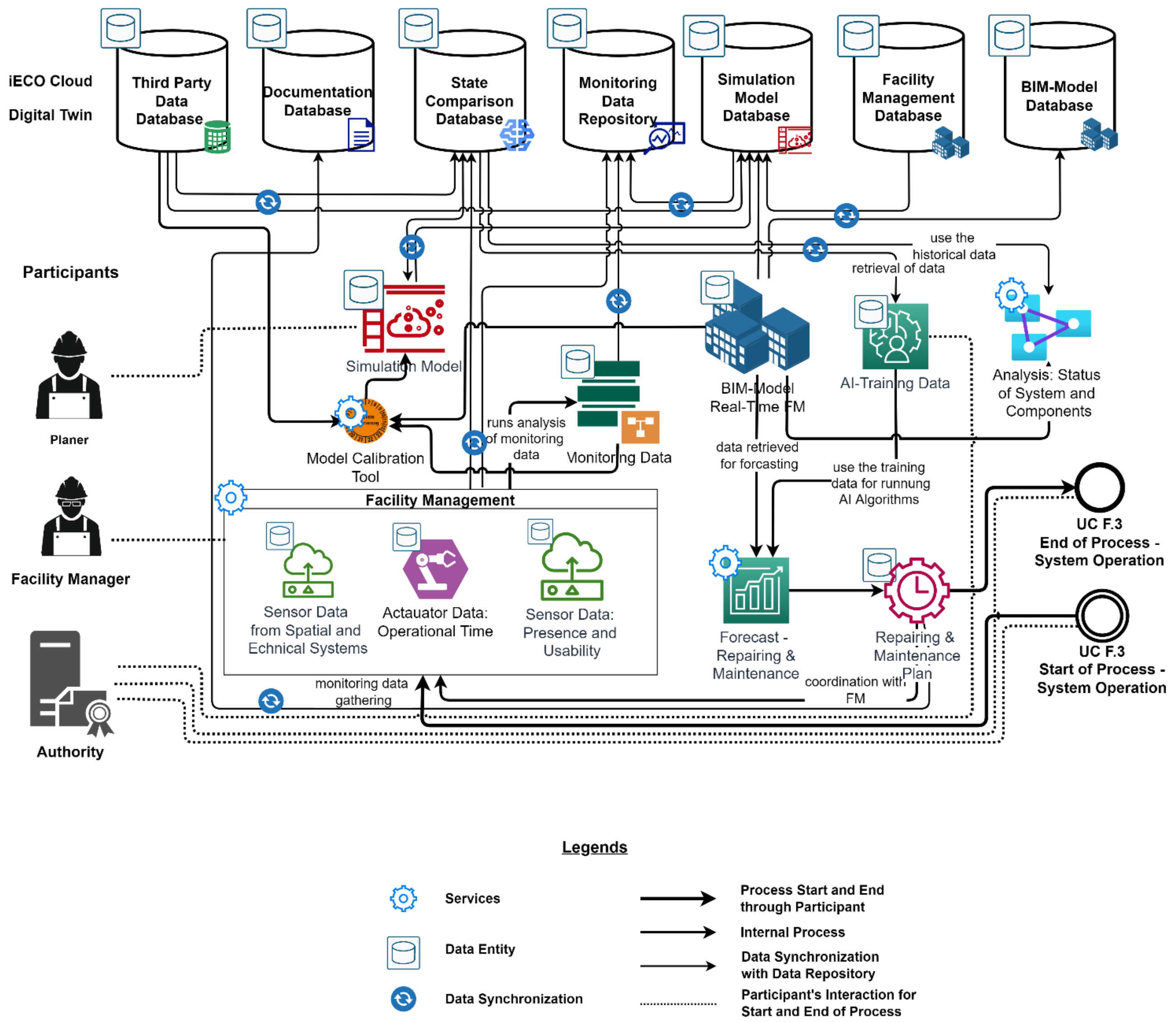
Attachment B.1: UC F.1 AI-led Documentation



Attachment B.2: UC F.2 AI-led Commissioning

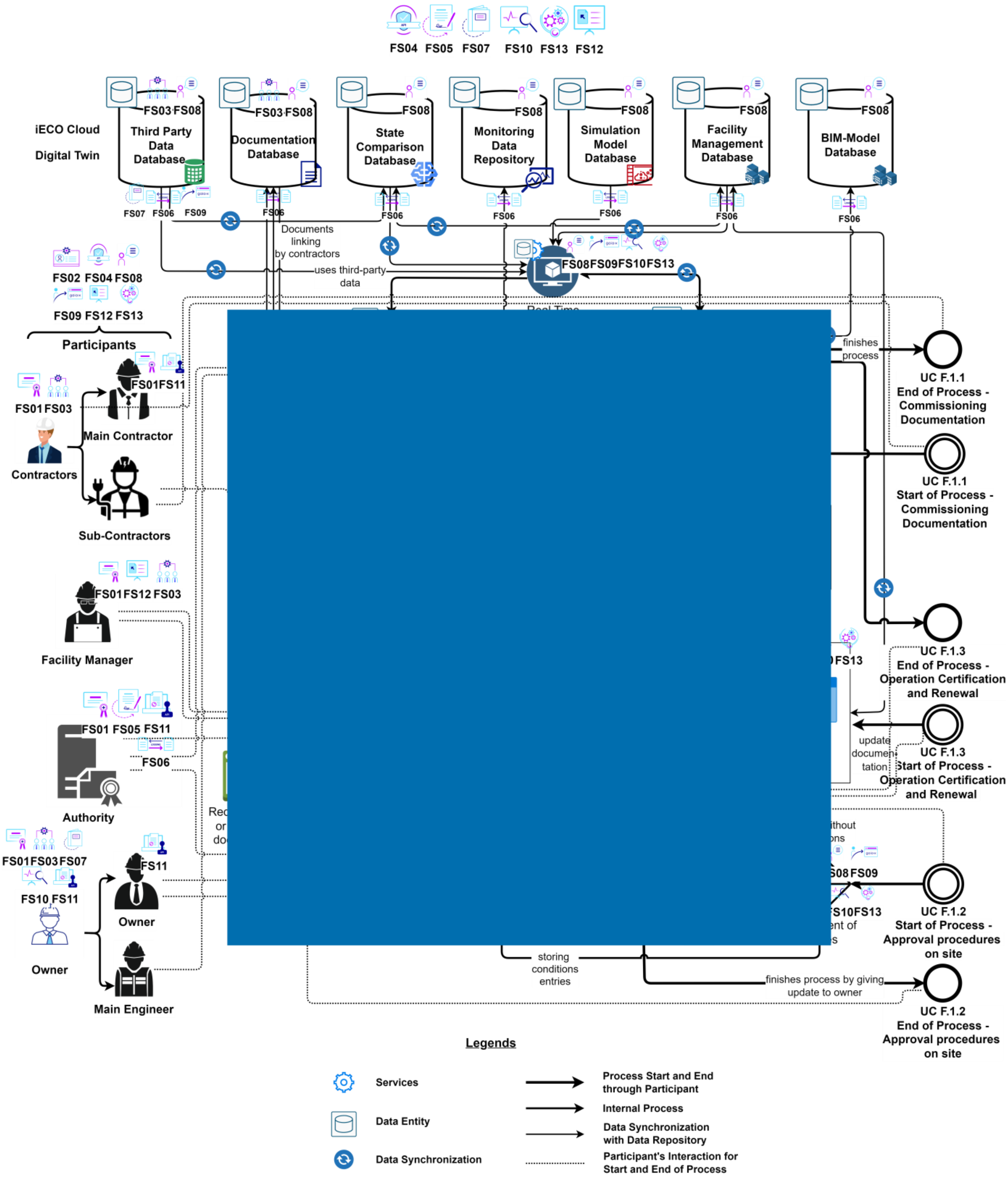


Attachment B.3: UC F.3 AI-led Building Operation

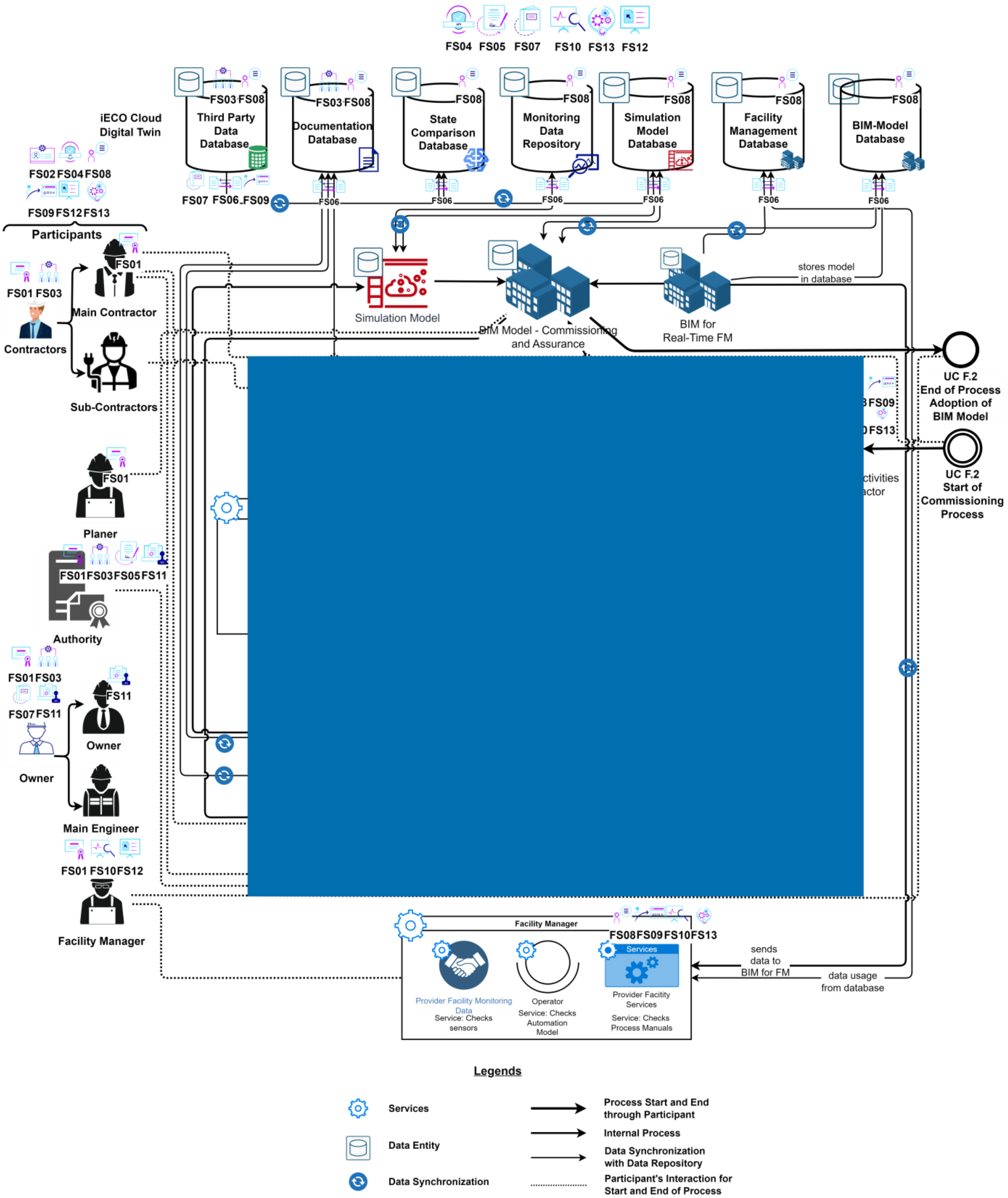


Attachment C

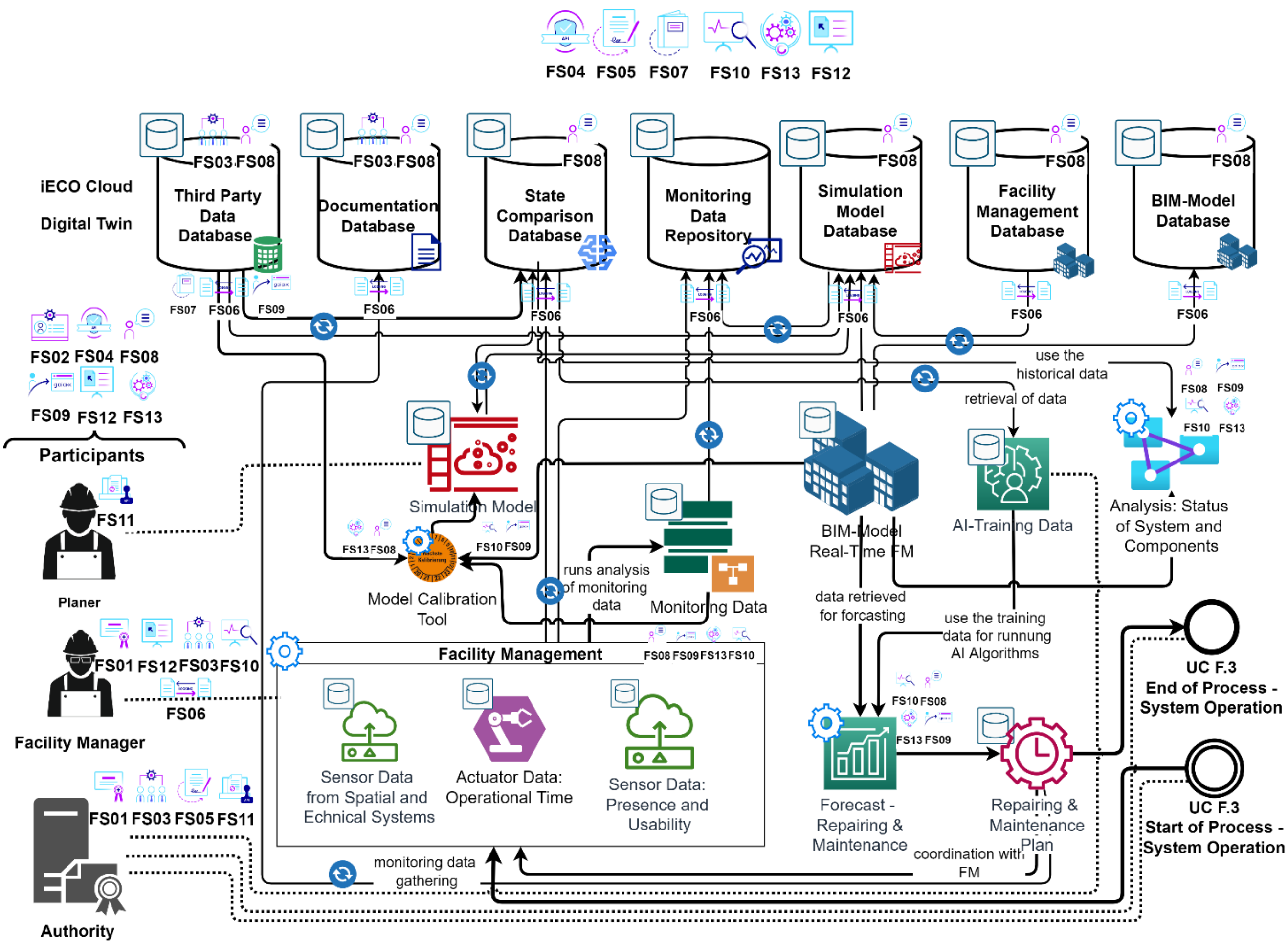
Attachment C.1: UC F.1 AI-led Documentation with GXFS



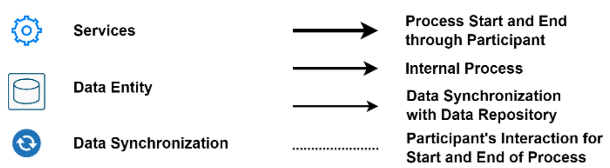
Attachment C.2: UC F.2 AI-led Commissioning with GXFS



Attachment C.3: UC F.2 AI-led Commissioning with GXFS



Legends



Declaration

I hereby declare that I wrote the present master thesis on my own. Only the sources and resources expressly named in the work were used. Literally or analogously adopted ideas I have identified as such.

I also assure that the present work has not yet been used as the basis for another examination procedure.

Munich, 19. March 2023 [redacted]

Pintukumar Ashokbhai Nakrani

Pintukumar Ashokbhai Nakrani

[redacted]

Email: pintukumar.nakrani@tum.de

Email: pintunakrani23@gmail.com