Roadmap for leveraging Smart Buildings

A practical roadmap for achieving asset management goals through data-driven building solutions

Joep van der Weijden (TU Delft), Joppe Stelloo (Heijmans), Elena Chochanova (TNO)

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BRAINS 4 BUILDINGS

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TU Delft

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4 Trends in Smart Buildings

Get your building ready for the future by understanding and implementing these smart building trends.

THE SMART BUILDING HYPE

Smart Buildings Market Overview

The smart buildings market growth is attributed to the rising adoption of IoT-enabled building management systems, growing awareness of space utilization, and increasing demand for energy-efficient systems.

72.6 USD Billion 2021

121.6 USD Billion 2026

CAGR of 10.9%

The global smart buildings market is expected worth USD 121.6 billion by 2026, growing at a CAGR of 10.9% during the forecast period.

Rise in adoption of IoT-enabled building management solution with increasing demand for energy efficient systems.

Government authorities are promoting practices to reduce energy consumption across building infrastructures to achieve sustainable goals.

North America is estimated to account for the largest market size of USD XX billion in 2021 and is expected to reach USD XX billion by 2026, at a CAGR of XX% during the forecast period.

The highest CAGR of APAC smart buildings market can be attributed to the increasing construction and industrial activities supported by various government initiatives.

Smart Buildings

Dankzij de nieuwste technol
gebouwen steeds intelligent
andere voor een optimale be

7 Smart Buil

As we step into 2024, the lan
is evolving rapidly, driven by technological advancements and changing societal needs. Smart buildings are no longer a futuristic concept but a present-day reality, shaping how we

70% (€900 billion last year) of the Smart Building Initiatives fail!

Digital Transformation Is Not About Technology

by Behnam Tabrizi, Ed Lam, Kirk Girard, and Vernon Irvin

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By Ryan Fletcher, Nick S

Connected b
what it will ta

Cobouw Aanbesteden Bouwkwaliteit Duurzaamheid Infra Innovatie Marktontwik

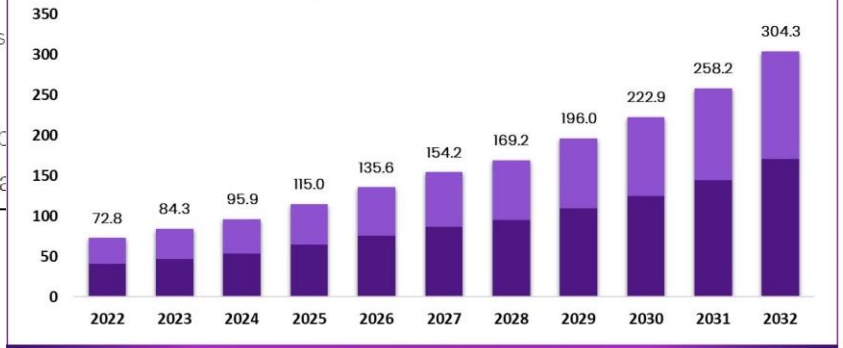
Elk kantoor een smart building

De ict-revolutie van de afgelopen tien jaar lijkt voorbijgegaan aan de gebouwtechniek. Deerns probeert de achterstand in te lopen met een

Global Smart Buildings Market

Size, by component, 2022-2032 (USD Billion)

Solution Services



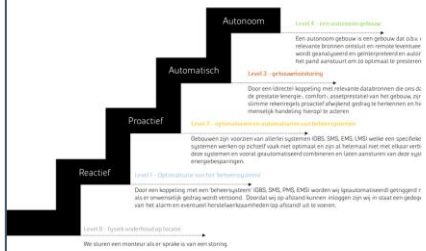
The Market will Grow At the CAGR of: 15.8% The forecasted market size for 2032 in USD: $304.3B market.us

'Iedereen wil opeens een smart building, maar heeft eigenlijk nog geen idee waarom precies'

'Gebouwen zijn verantwoordelijk voor 40% van het wereldwijde energieverbruik en het is van begin af aan de missie van

1 – WE'RE STARTING WITHOUT A CLEAR DEFINITION OF THE PROBLEM

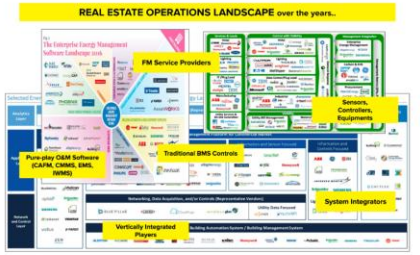
+ The 'WHY' is not clear (what problem are we solving?)
+ the means justify the ends



2 – LEARN HOW TO WALK BEFORE WE START RUNNING

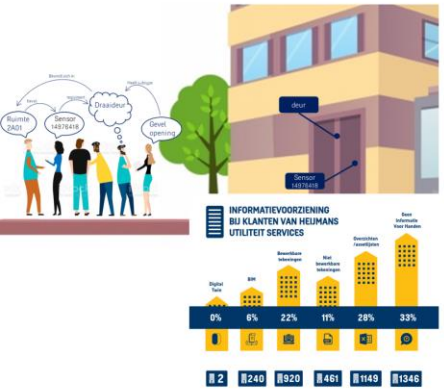
+ "70% of building management systems are not properly configured (and therefore do not operate optimally).
+ Research indicates that 80% of buildings already have the capabilities that the Facility Manager desires."

[1]https://www.installatietotaal.nl/news/item/70-van-koelinstallaties-niet-optimaal/



3 - SMART BUILDINGS ARE NOT SCALEBLE

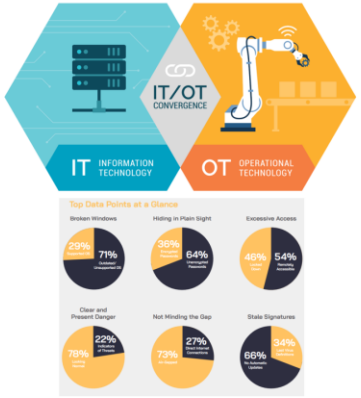
+ "The ecosystem of most suppliers is closed.
+ Each building is unique (in age, manufacturers, protocols)."



4 – DE REAL ESTATE DATA IS OFTEN INCORRECT OR NOT AVAILABLE

+ So many standards
+ The installations operate independently from each other (And data is not being reused)

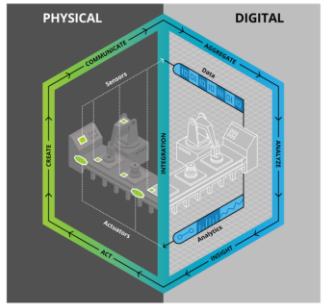
" 7 REASONS WHY YOU SHOULD **NOT** START WITH A SMART BUILDING„



5 – THE RISKS OF CYBERSECURITY ARE INCREASING

1. The potential attack surface is expanding
   - Target1
2. OT SYTEMS are old
   - 71% heeft verouderde of niet ondersteunde besturingssystemen2

1: www.computerworld.com/article/2487452/target-attack-shows-danger-of-remotely-accessible-hvac-systems.html
2: CyberX - Global IoT and ICS risk report (2020)



6 – WE DO NOT CLOSE THE CIRCLE

+ We elevate the means to the goal: a smart building is not about technology.
+ The resources don't make a building smart; it's the end result that does

7 – PEOPLE ARE AFRAID OF SMART BUILDINGS

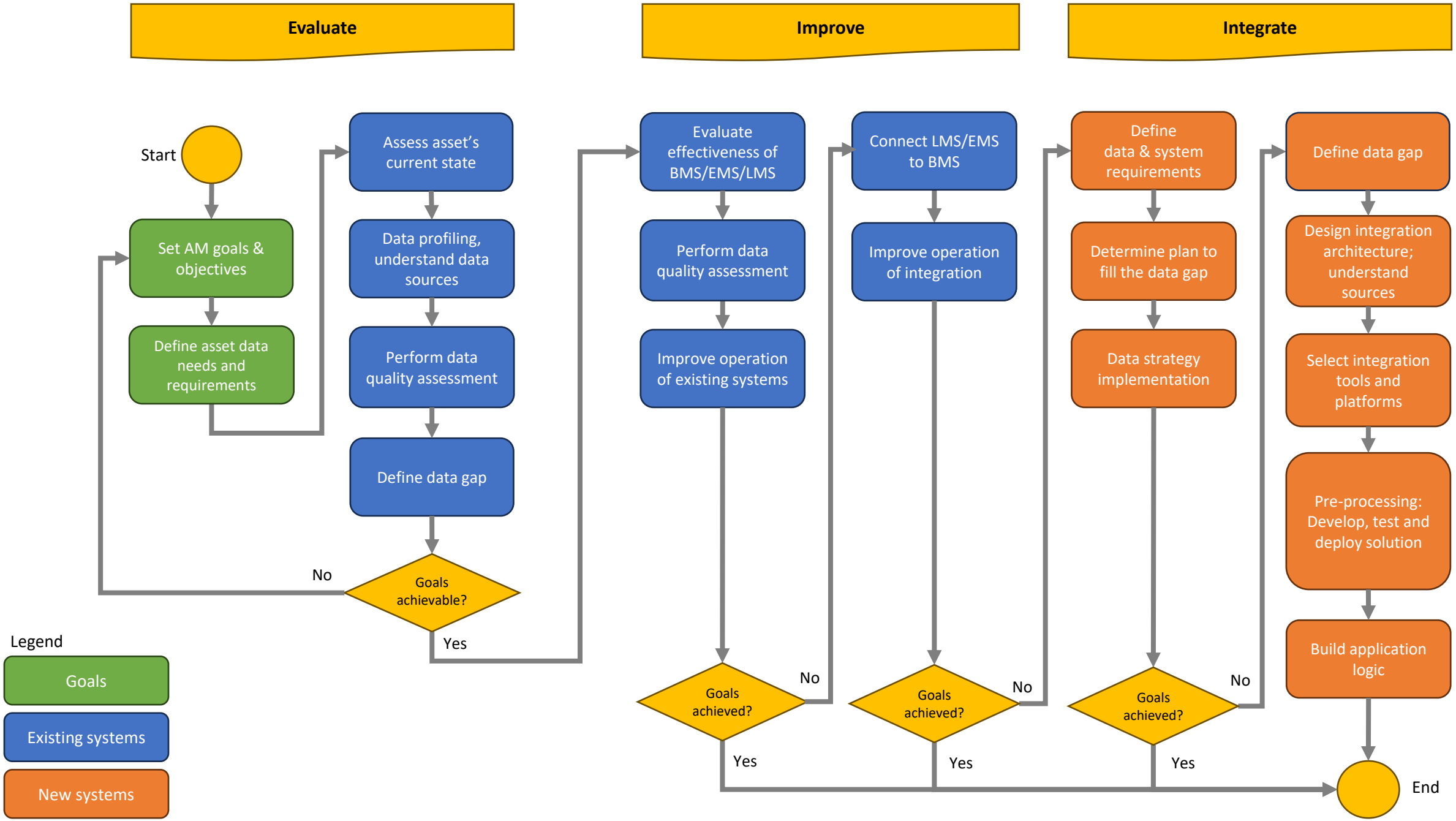
+ Technology creates the opposite of the intended goal.
+ History teaches us that technological advancements always come with drawbacks.
+ The question is: *What drawbacks will the developments in Smart Buildings bring?*

Goal of this handbook

1. Create **awareness** about the current challenges in the industry and how they can be overcome with both **high-tech** and **low-tech** solutions;

2. Illustrate that a smart building is a **tool** and not a goal in itself to achieve a (set of) predefined asset management **goal(s)**;

3. Provide the different stakeholders in the smart building value chain with a **practical roadmap** for achieving asset management goals through data-driven solutions, by starting with **data integration**.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Assess asset's current state
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Perform data quality assessment
Define data gap
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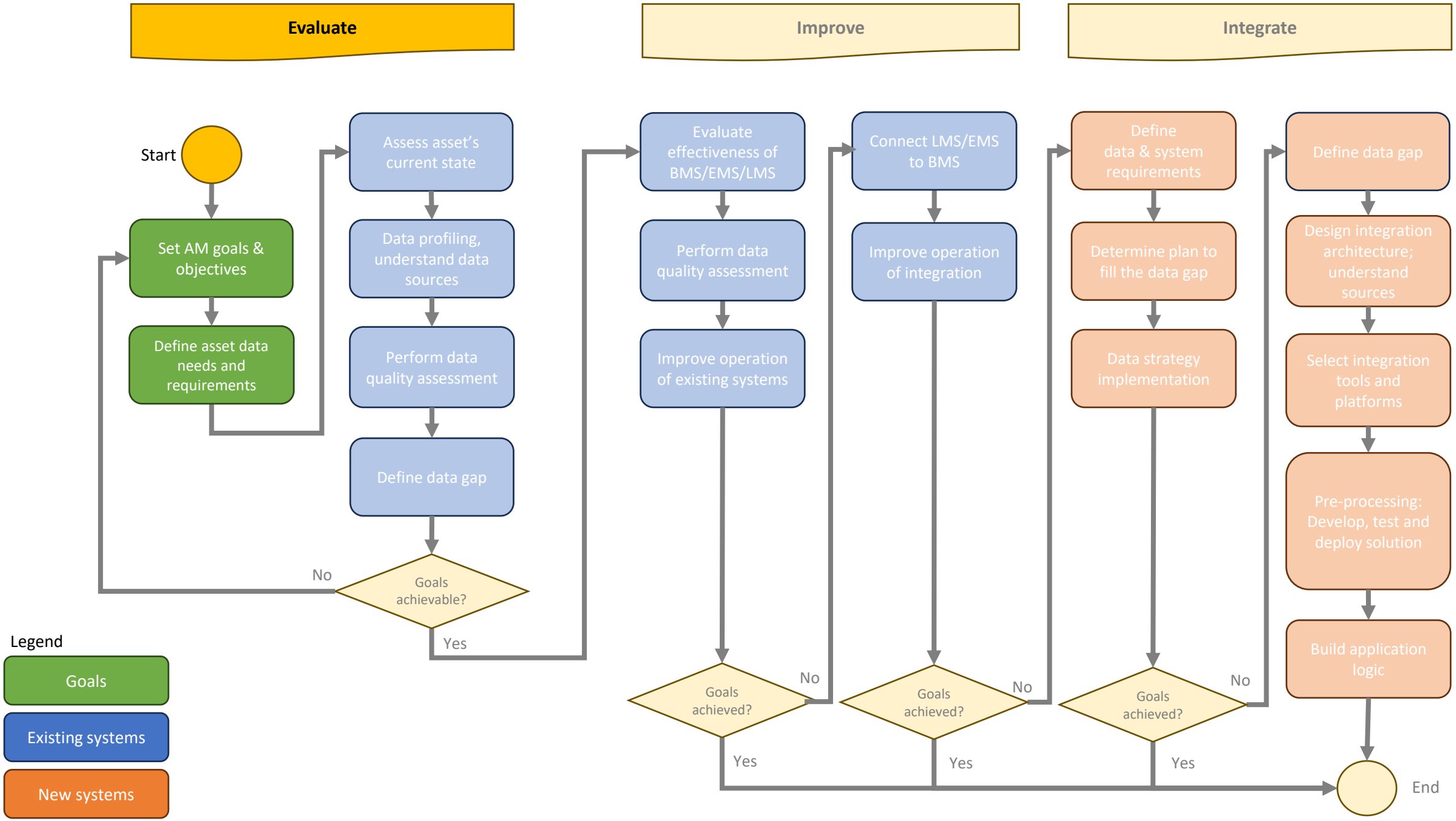
New systems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“Help the customer to define and prioritize her ambitions (goals & objectives)„

Strategy & Policy

Level: Strategic

What: Organizational strategic plans and policy documents

Why: For effective asset management it is essential to align the AM goals and objectives with the organization’s strategic plans.

Who: Defined usually by the board of directors and/or the asset owner.

AM goals, objectives and plan

Level: Strategic / Tactic

What: SAMP (Strategic Asset Management Plan) and AMP (Asset Management Plan)[2]

Why: SAMP is used to translate the organizational goals into AM goals and objectives. AMP is used to describe the activities and planning needed to realize the AM goals and objectives.

Who: Put together by the asset owner or asset manager, with possible input from the facility manager.

Information Requirements

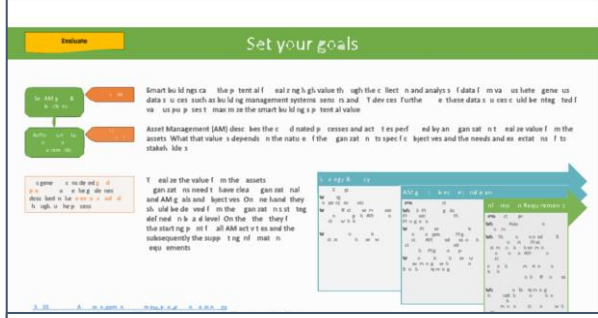
Level: Tactic / Operational

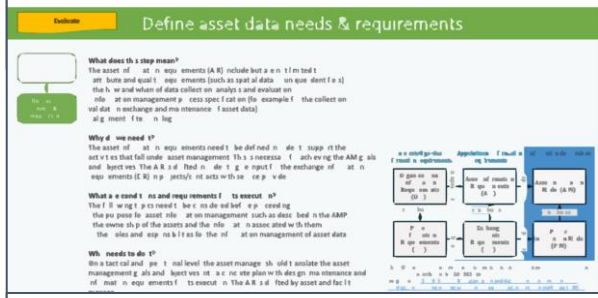
What: AIR (Asset Information Requirements)[3]

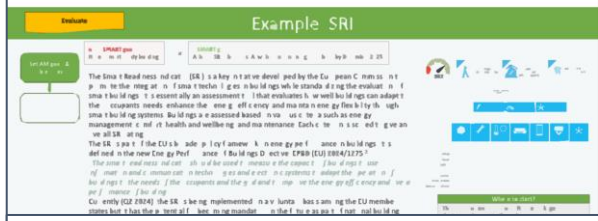
Why: The organization needs to define its AIR to support its AM activities, systems and the achievement of its organizational and AM goals and objectives.

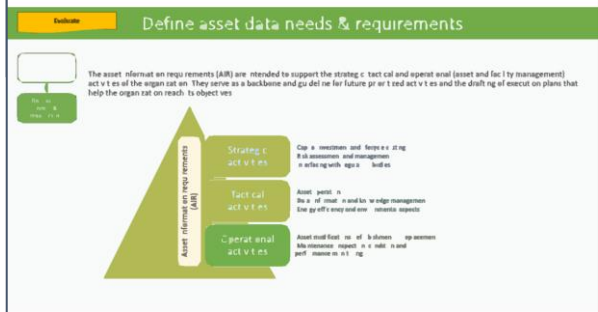
In doing that, it is important to ensure that there is consistency and traceability between the different types of data.

Who: Asset and facility managers should draft the AIR and use them to define exchange information requirement in projects/contracts with service providers.

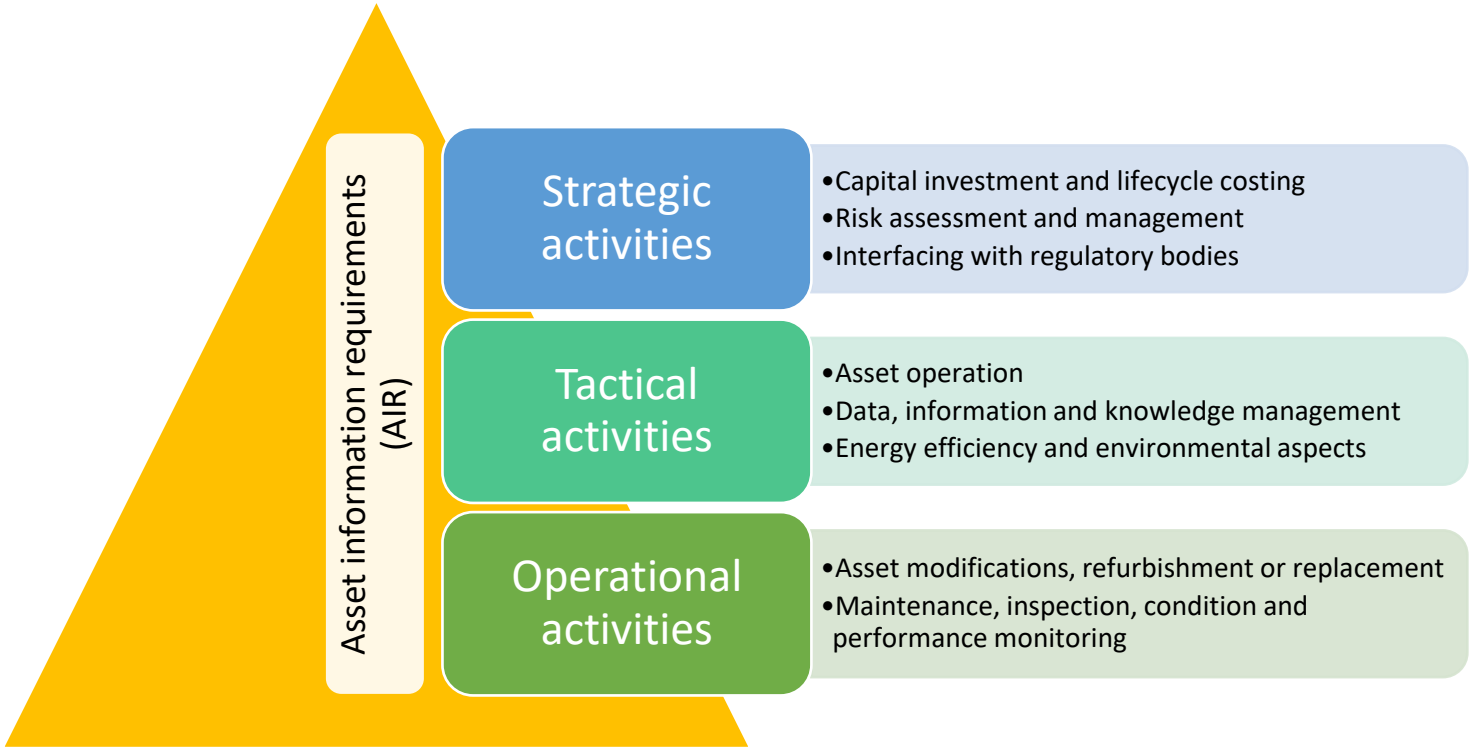


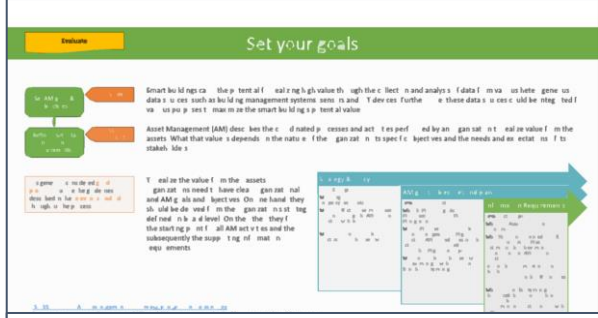


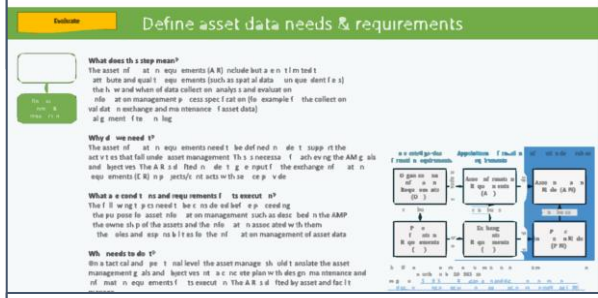


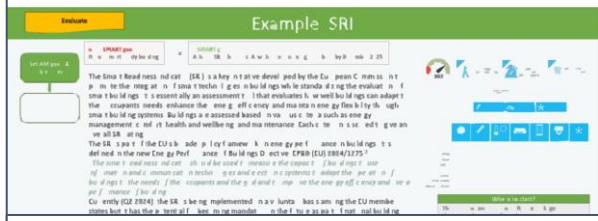


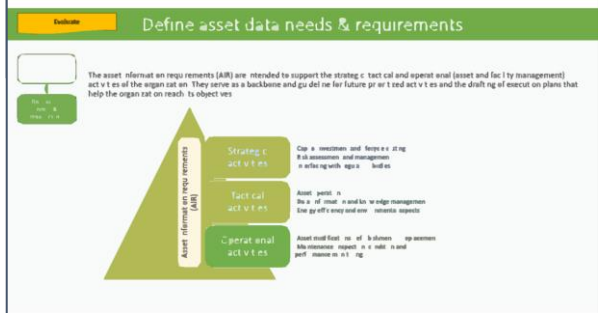
“and translate those ambitions into clear asset data needs & requirements„

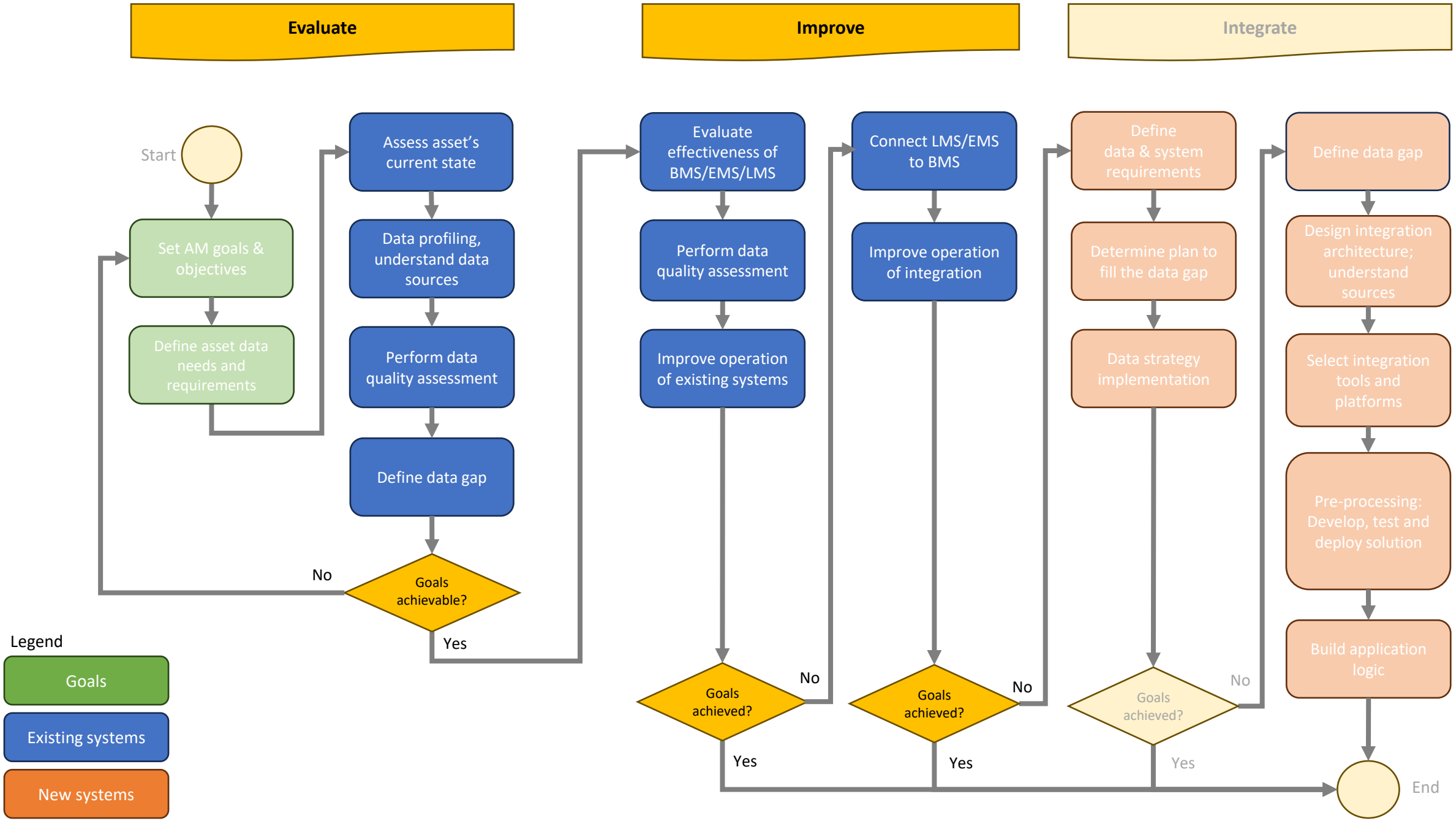








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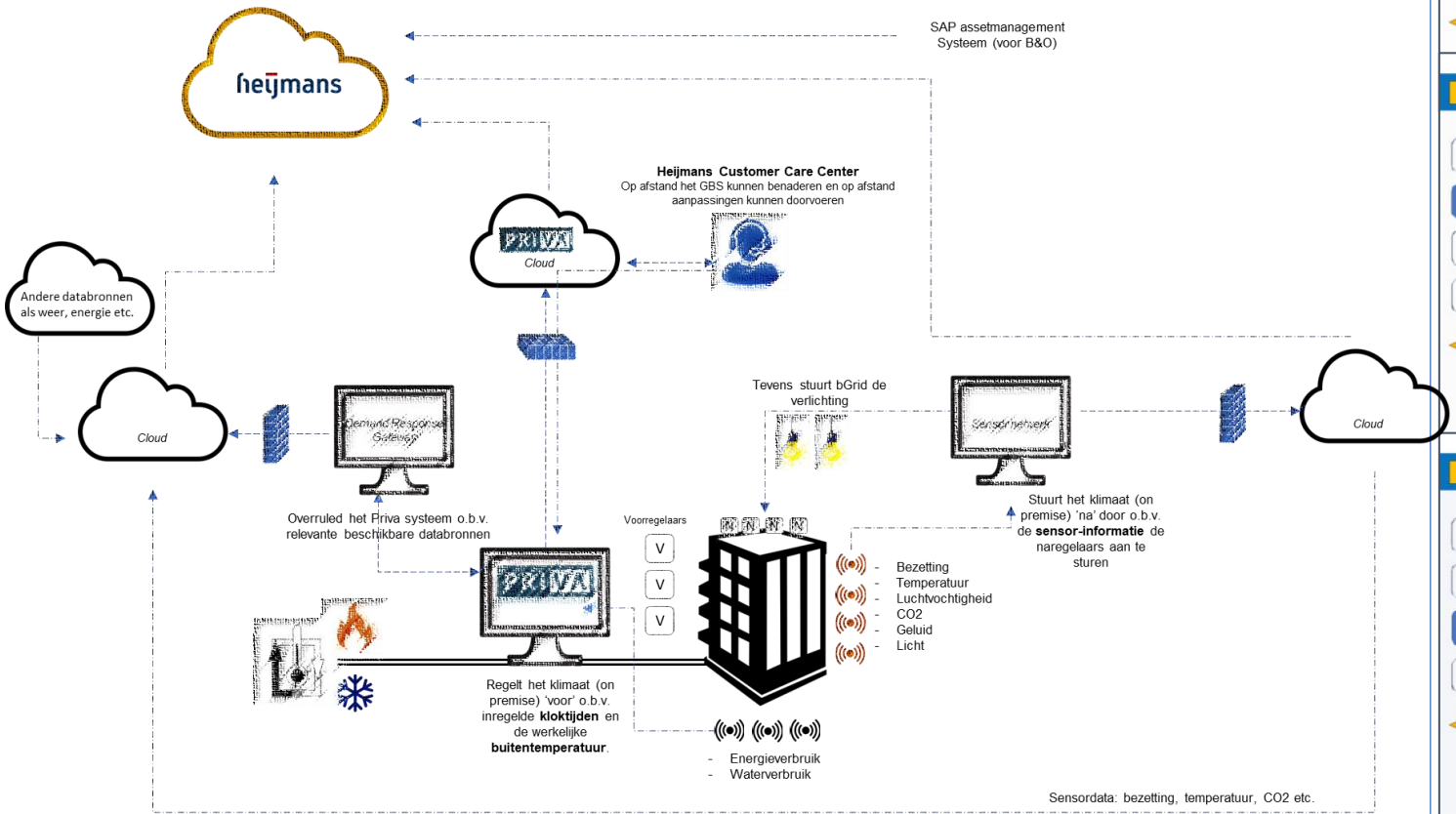
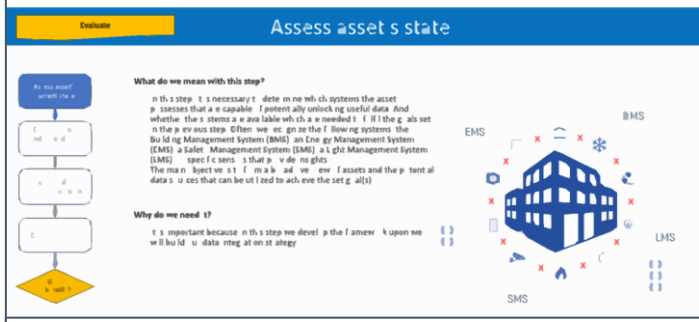
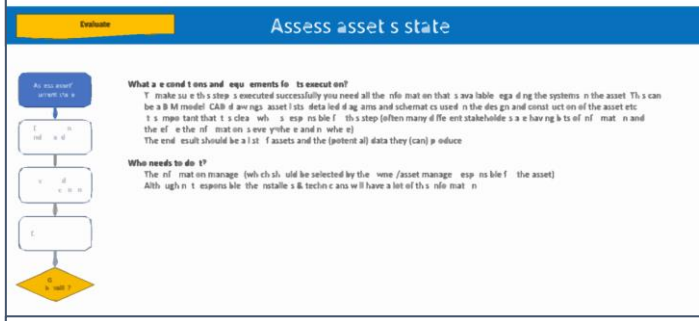
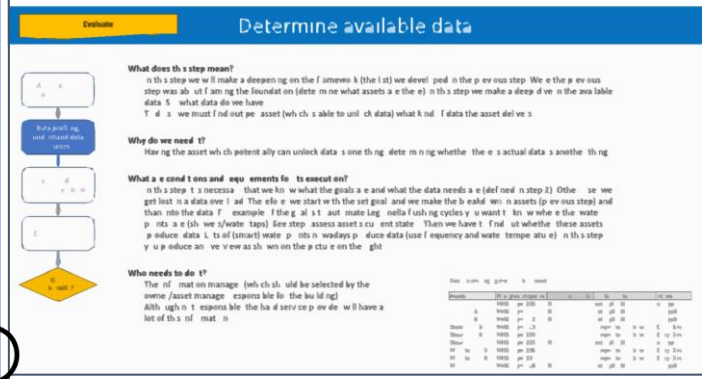
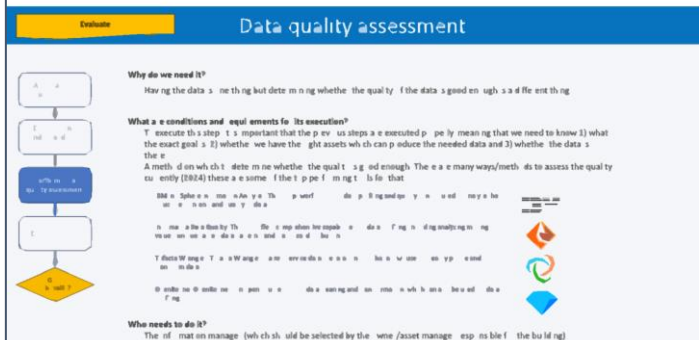
“Create a functional (IT/data) design (as is & to be) and define data gaps„







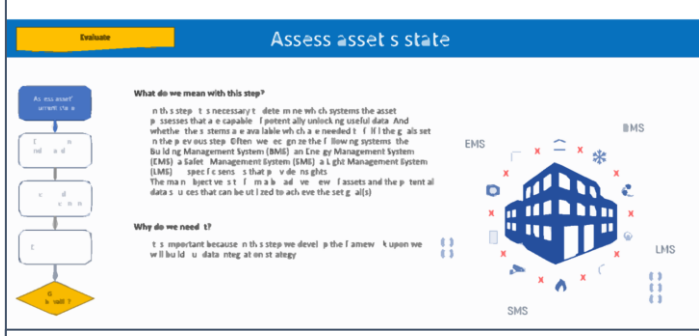


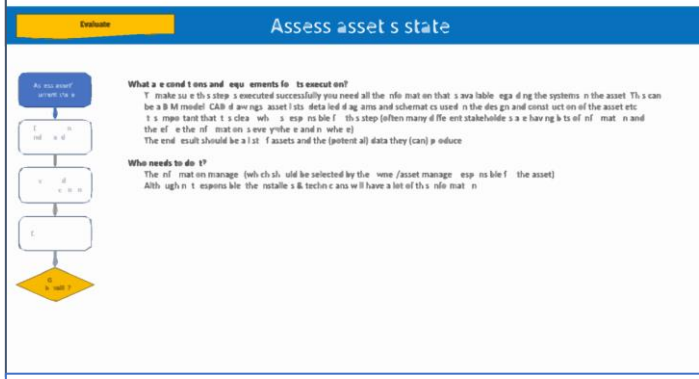


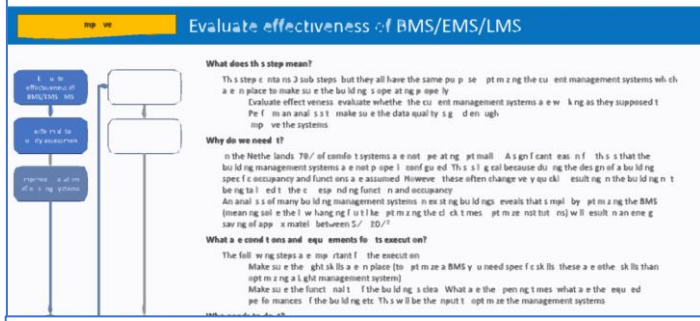
“Evaluate (and optimize) the effectiveness of existing systems (BMS)”

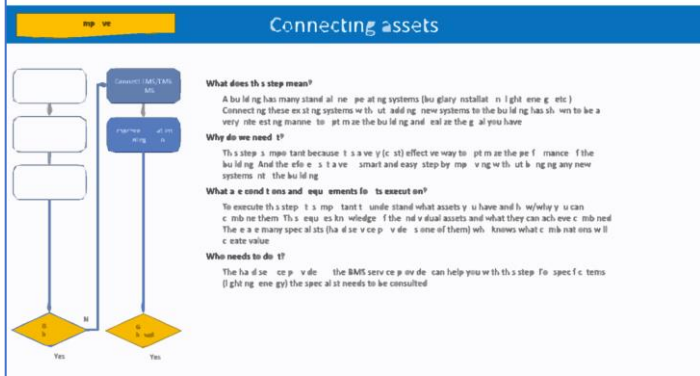
70% van koelinstallaties werkt niet optimaal

Een goed ingeregeld klimaatsysteem houdt het binnenklimaat aangenaam. Ongeveer 70% van de klimaatinstallaties werkt niet optimaal. Een kwart gebruikt te veel energie. Bijvoorbeeld doordat leidingen niet geïsoleerd zijn. Hier is veel energiewinst te halen.

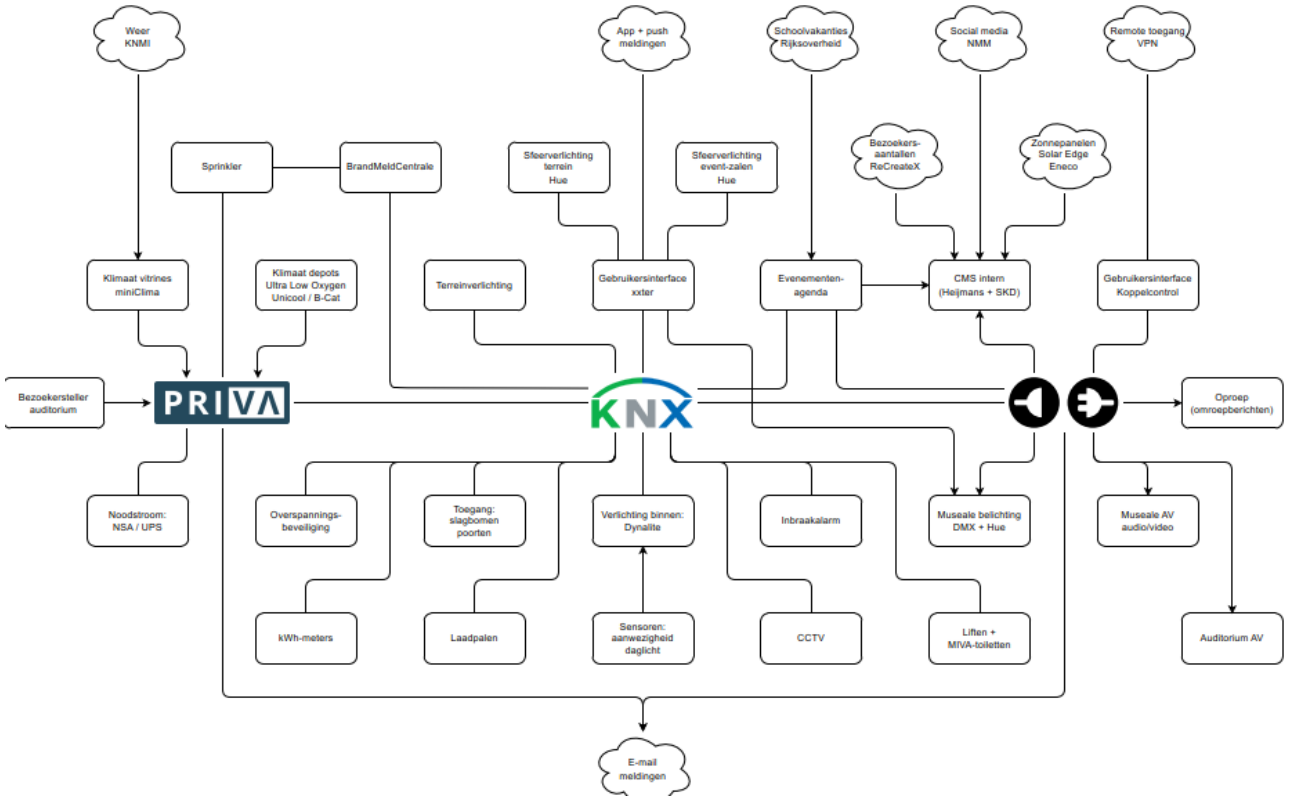


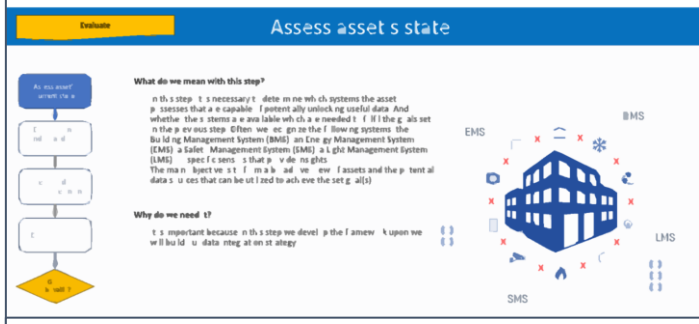


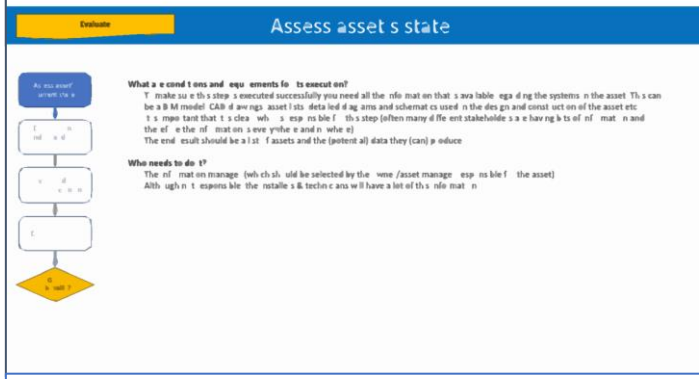


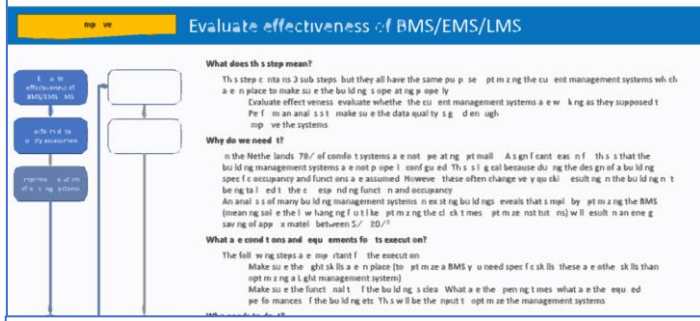


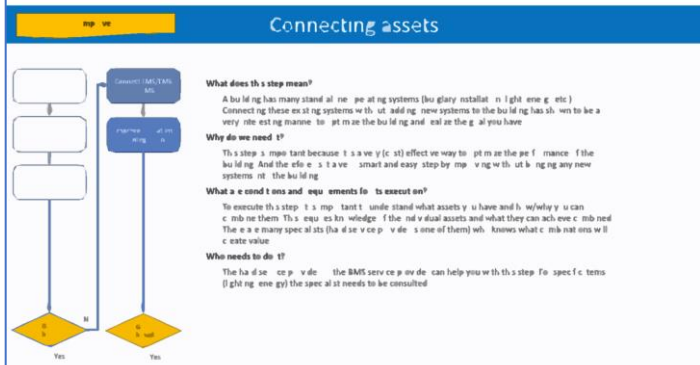
“Pick the low-hanging fruit”





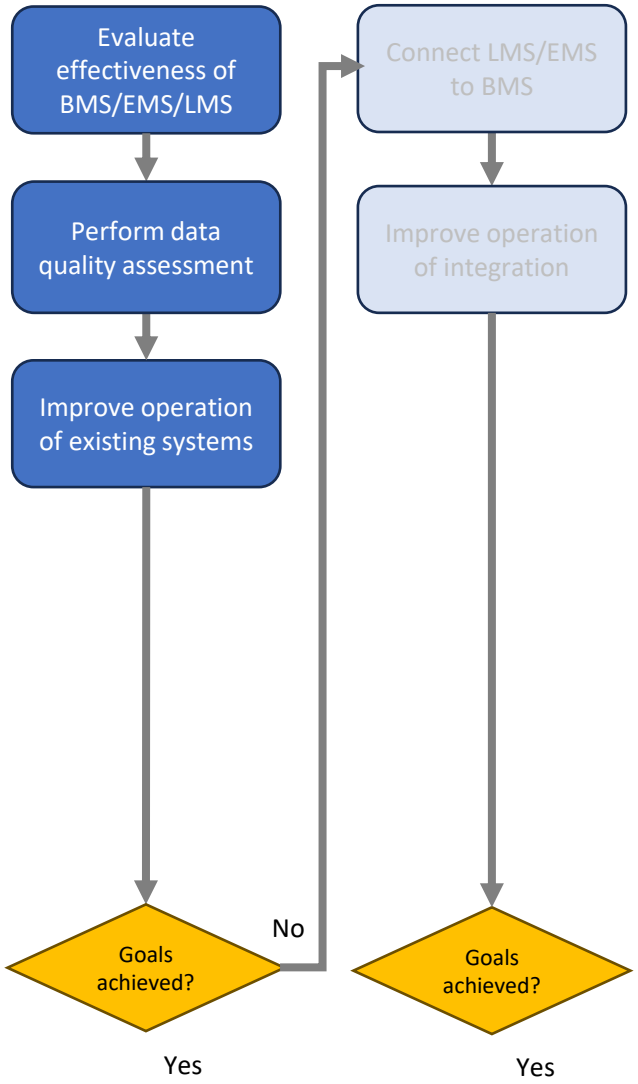






Improve

Evaluate effectiveness of BMS/EMS/LMS



What does this step mean?

- This step contains 3 sub-steps, but they all have the same purpose: optimizing the current management systems which are in place to make sure the building is operating properly.
  - Evaluate effectiveness: evaluate whether the current management systems are working as they supposed to
  - Perform an analysis to make sure the data quality is good enough
  - Improve the systems

Why do we need it?

- In the Netherlands, 70% of comfort systems are not operating optimally[1]. A significant reason for this is that the building management systems are not properly configured. This is logical because during the design of a building, specific occupancy and functions are assumed. However, these often change very quickly, resulting in the building not being tailored to the corresponding function and occupancy.
- An analysis of many building management systems in existing buildings reveals that simply by optimizing the BMS (meaning solve the low-hanging fruit like optimizing the clock-times, optimize institutions) will result in an energy saving of approximately between 5% - 20%[2].

What are conditions and requirements for its execution?

- The following steps are important for the execution:
  - Make sure the right skills are in place (to optimize a BMS you need specific skills; these are other skills than optimizing a Light management system).
  - Make sure the functionality of the building is clear. What are the opening times, what are the required performances of the building etc. This will be the input to optimize the management systems.

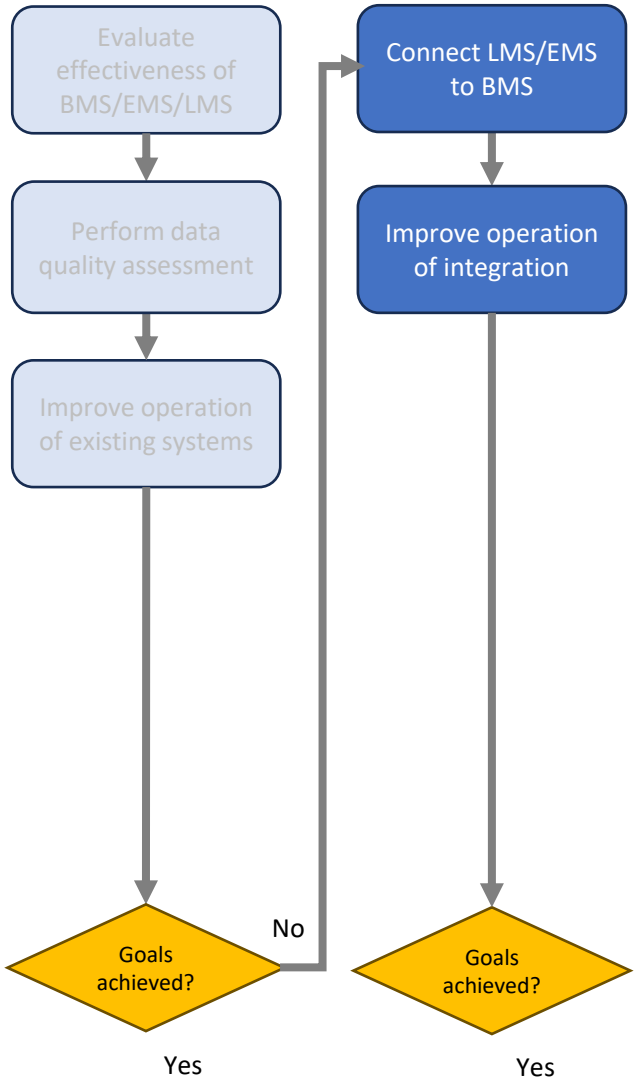
Who needs to do it?

- The hard service provider or the BMS service provider can help you with this step. For specific items (lighting, energy) the specialist needs to be consulted.

[1] 70% van koelinstallaties werkt niet optimaal | (installatietotaal.nl)
[2] Energy Efficiency – Lawrence Berkeley National Laboratory (lbl.gov)

Improve

Connecting assets



What does this step mean?

- A building has many stand-alone operating systems (burglary installation, light, energy etc.). Connecting these existing systems without 'adding' new systems to the building has shown to be a very interesting manner to optimize the building and realize the goal you have.

Why do we need it?

- This step is important because it is a very (cost) effective way to optimize the performance of the building. And therefore, is it a very 'smart and easy' step by improving without bringing any new systems into the building.

What are conditions and requirements for its execution?

- To execute this step, it is important to understand what assets you have and how/why you can combine them. This requires knowledge of the individual assets and what they can achieve combined. There are many specialists (hard service provider is one of them) who knows what combinations will create value.

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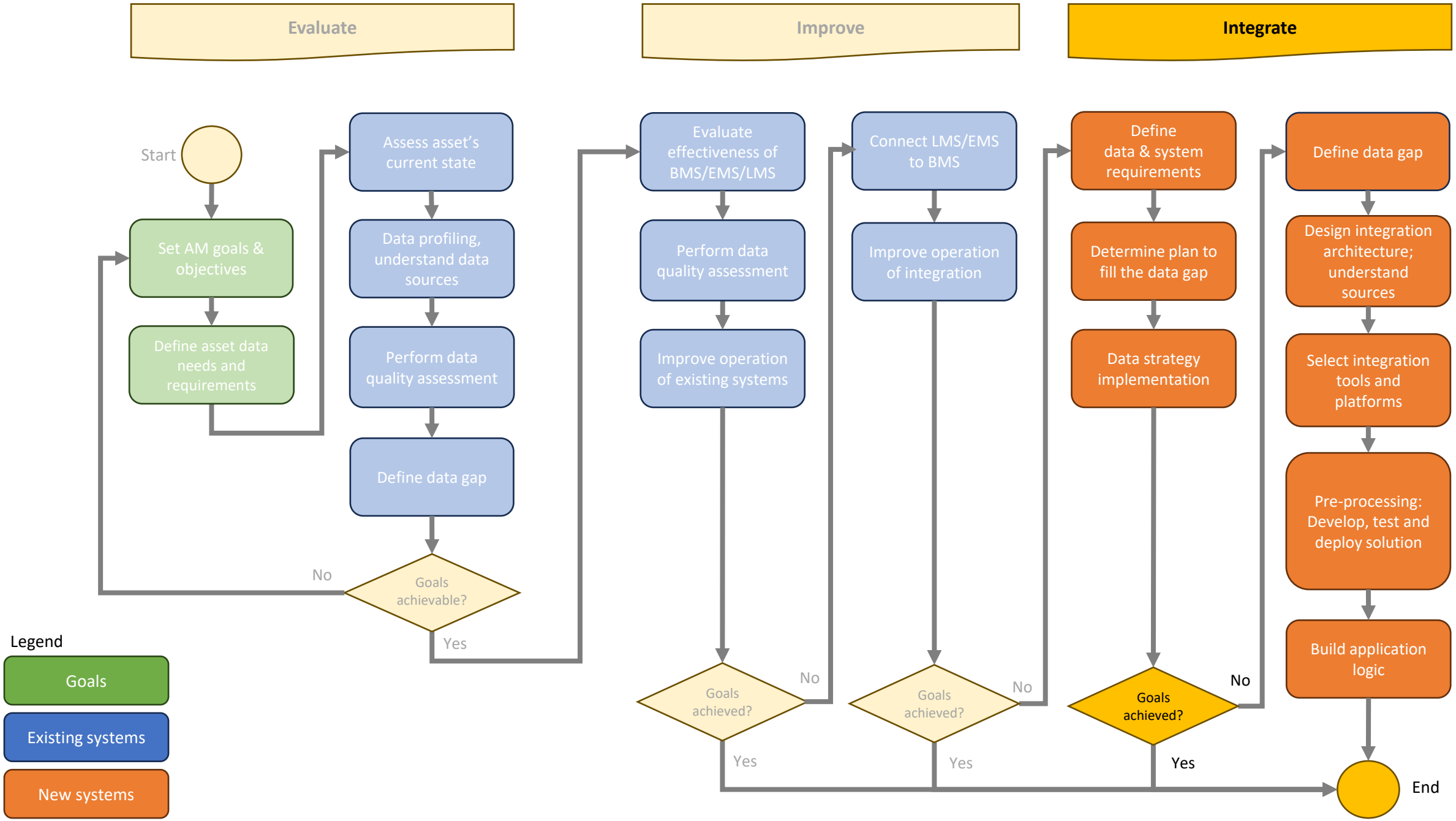
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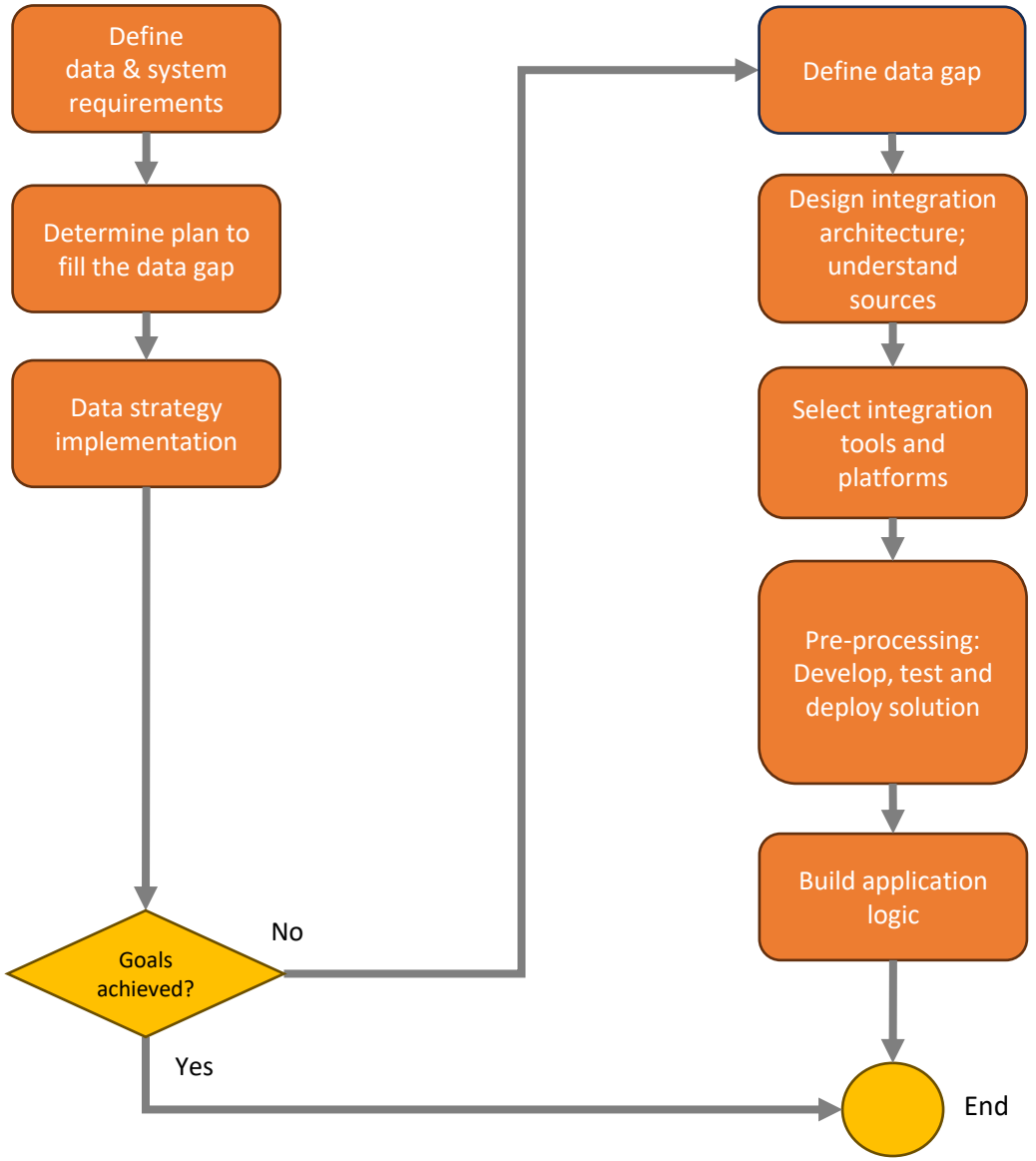
Integrate

Extend



Integrate

Define data & system requirements

Integrate

What

Questions to ask:

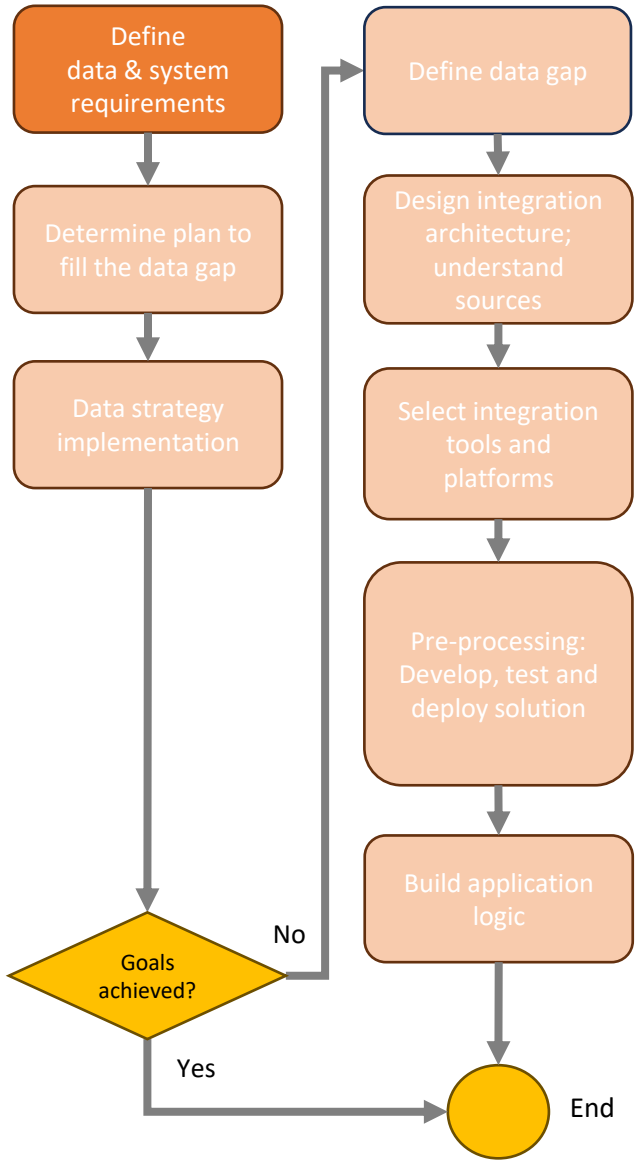
- Which type of sensors/actuators need to be installed?
- Which communication protocol do these sensors use?
- Which communication protocols are supported by my BMS?
- What is the measurement frequency?

Why

System requirements and data requirements

Who

Product developers and consultants, building and facility managers



Install additional monitoring

Integrate

What

Questions which need to be answered:

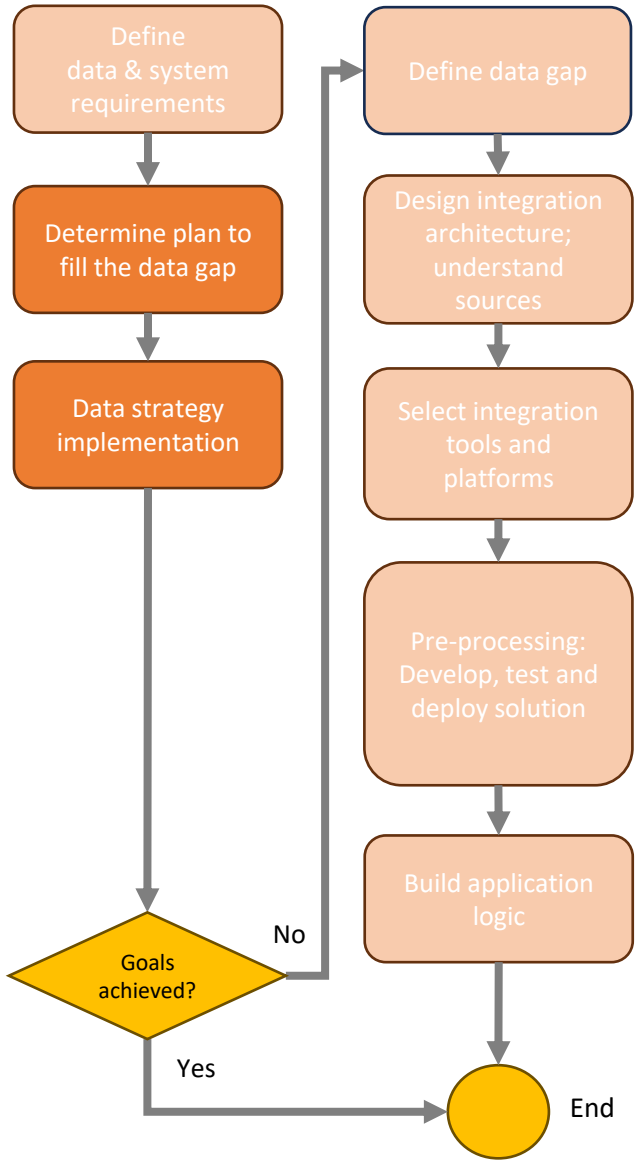
- Where do we install these sensors and control valves?
- What is the prioritization of the identified installations?
- What are the costs involved with filling these gaps?

Why

budget and time constraints.

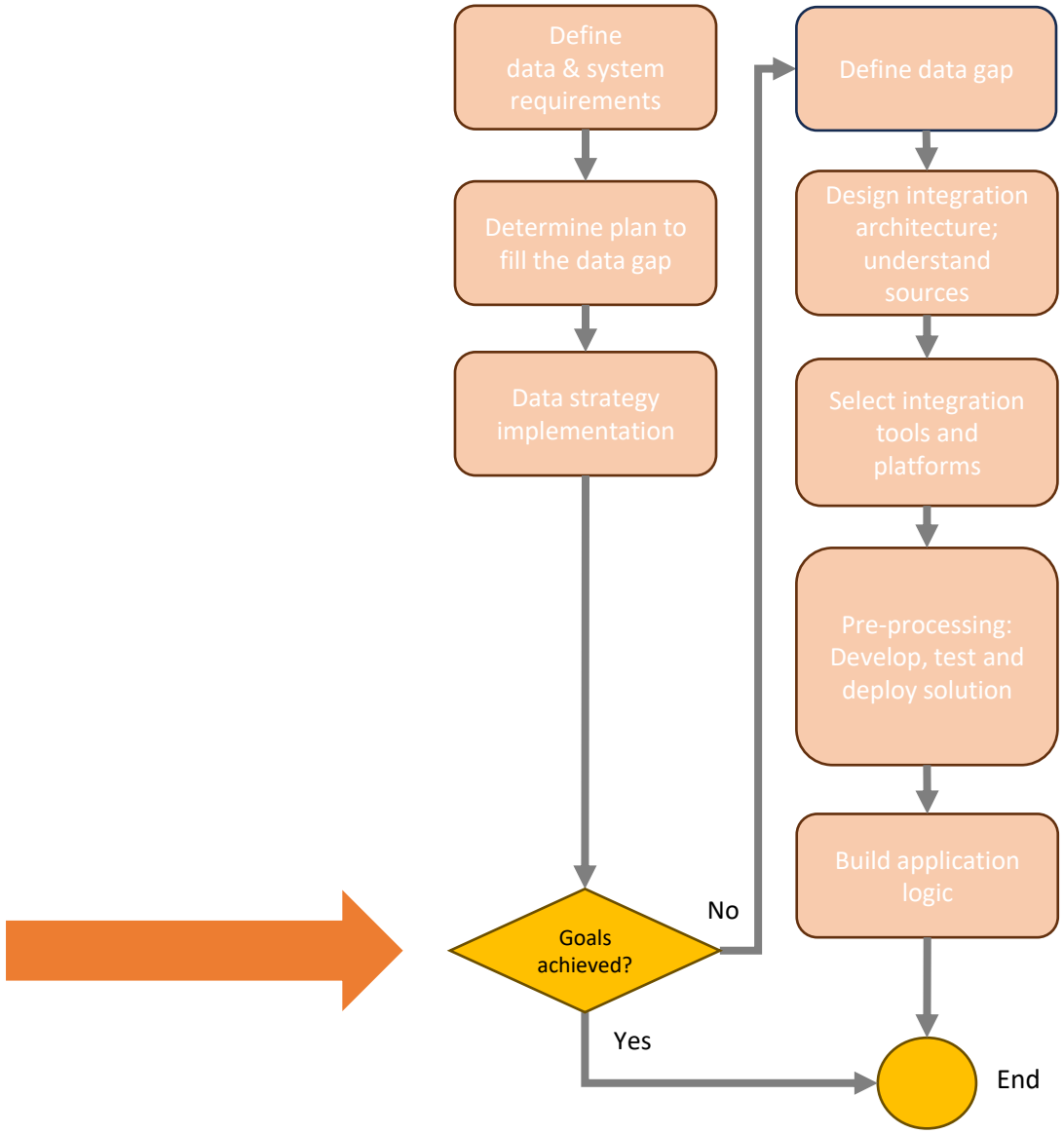
Who

Building- and facility managers, installers.



Install additional monitoring

Integrate



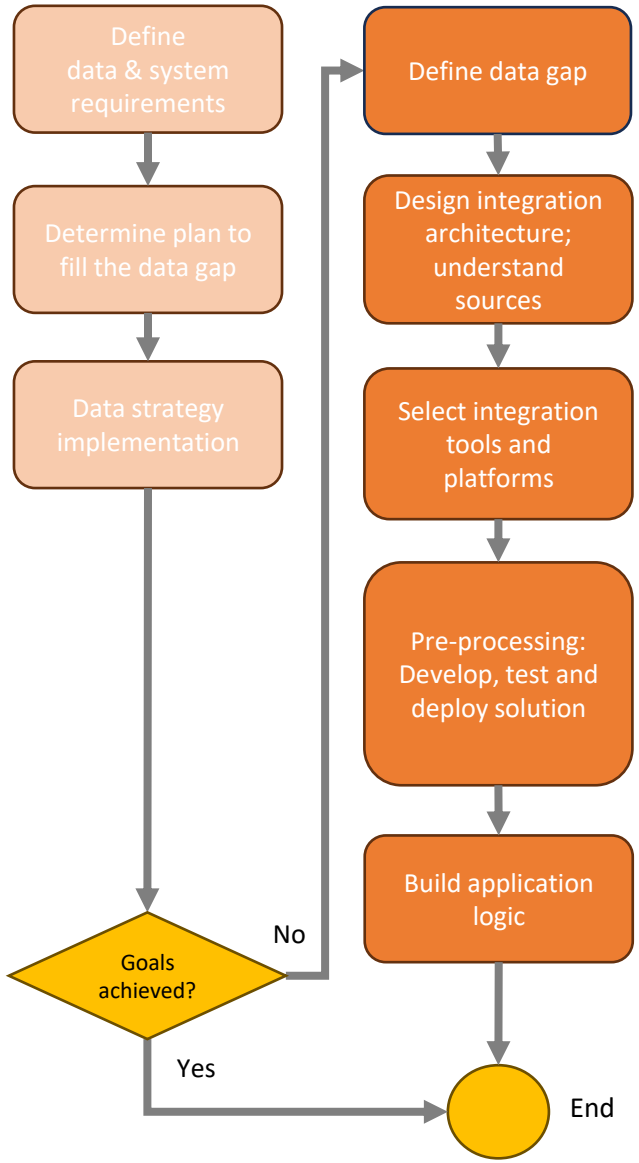
Data integration

Integrate

Operational and contextual data from various sources and systems:

- time series data
- contextual building data (linked data)

Lack of interoperability



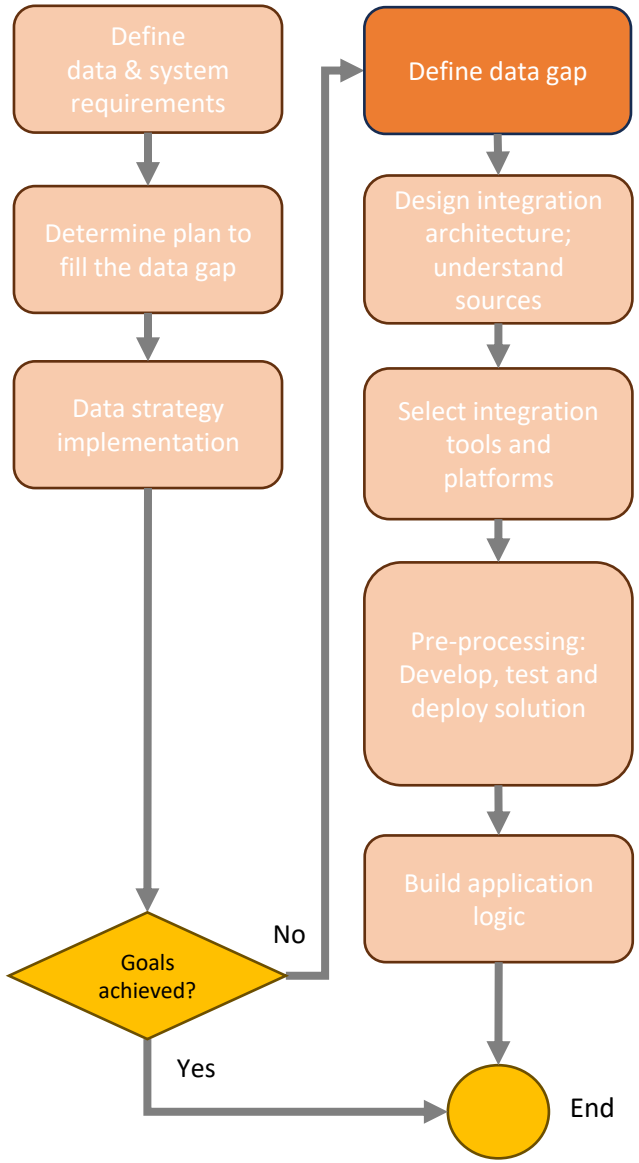
Define data gap

Integrate

What does this step mean?
In this step, it is required to think about the asset management goals and how data/information can be used to achieve these goals.

Why do we need it?
Without taking the time to think about the remaining gaps, there is no end goal to work towards while integrating different types of data.

Who needs to do it?
Building- and facility managers, installers



Integration architecture

Integrate

What does this step mean?

Smart buildings need to rely on a well-defined system architecture and Application Programming Interfaces (APIs) that enable both the integration of diverse systems and datasets and the orchestration of various services.

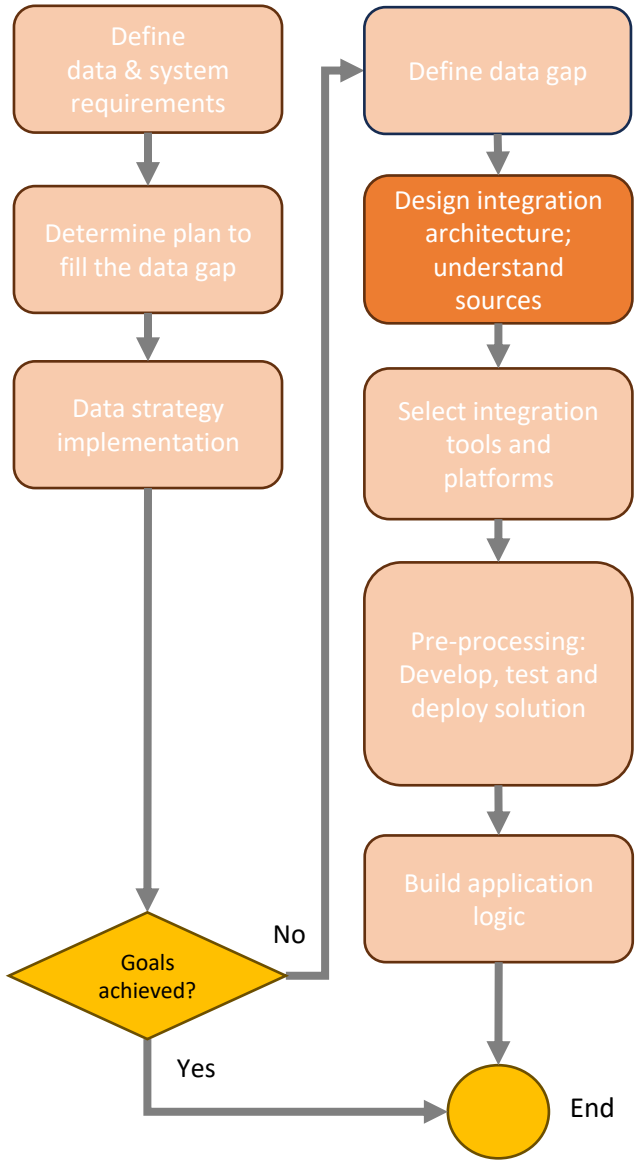
- Choose an appropriate integration architecture (e.g., centralized, decentralized, hybrid) based on the scale and complexity of the BMS.
- Design data flow diagrams to visualize the movement and transformation of data across systems.

Why do we need it?

Each individual building is unique, and path dependency plays a role, so developing a 'one size fits all' system architecture is impossible.

Who needs to do it?

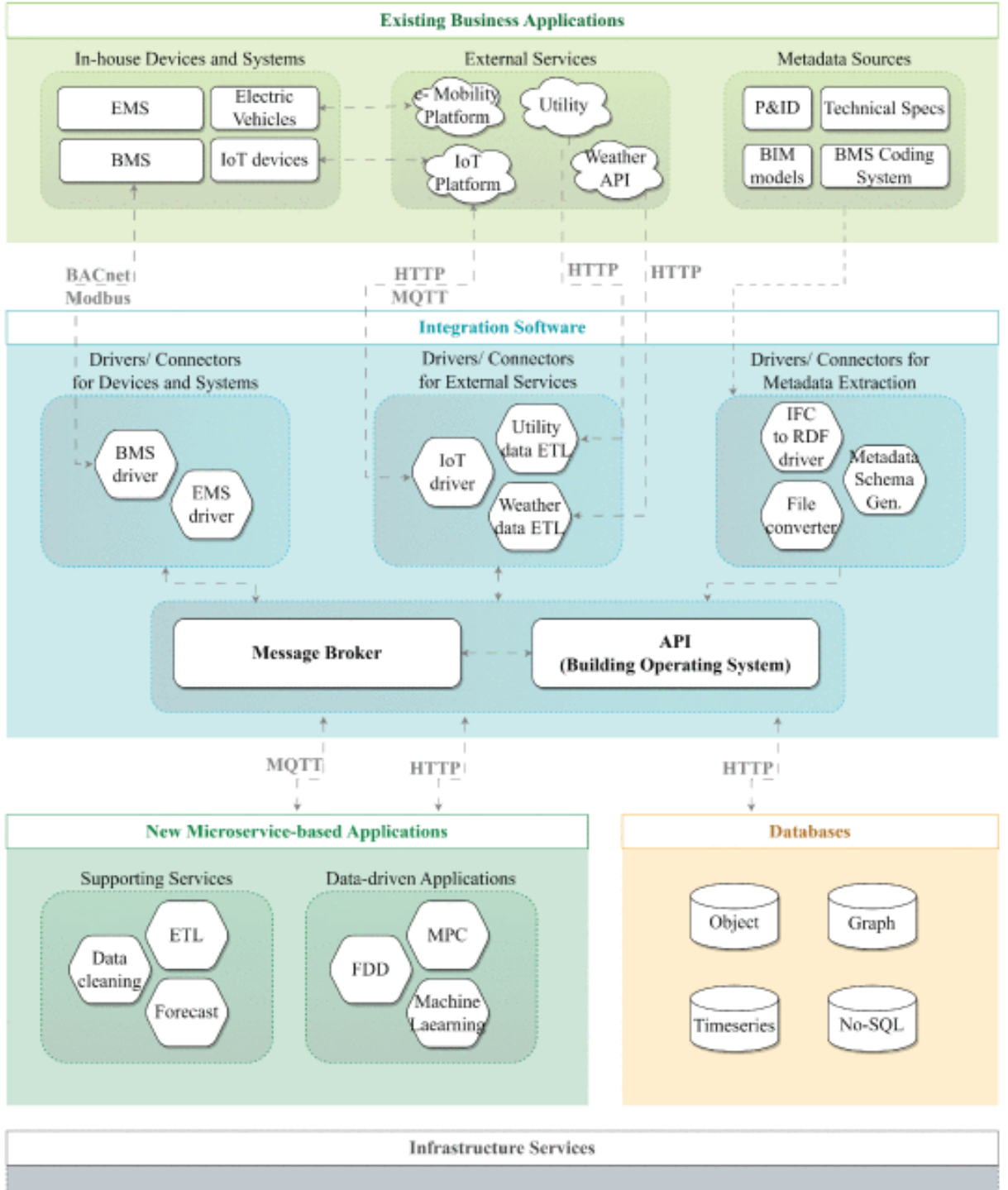
Data(base) engineer, building and facility managers



Reference architecture

The choice of a message broker, time series database, drivers and metadata database should be guided by the specific requirements of the BMS in terms of scalability, performance, data types, and operational environment.

It is also important to consider how these components integrate with each other to create a cohesive data integration ecosystem.



Source: L. Chamari, E. Petrova and P. Pauwels, "An End-to-End Implementation of a Service-Oriented Architecture for Data-Driven Smart Buildings," in IEEE Access, vol. 11, pp. 117261-117281, 2023, doi: 10.1109/ACCESS.2023.3325767

Message broker

Integrate

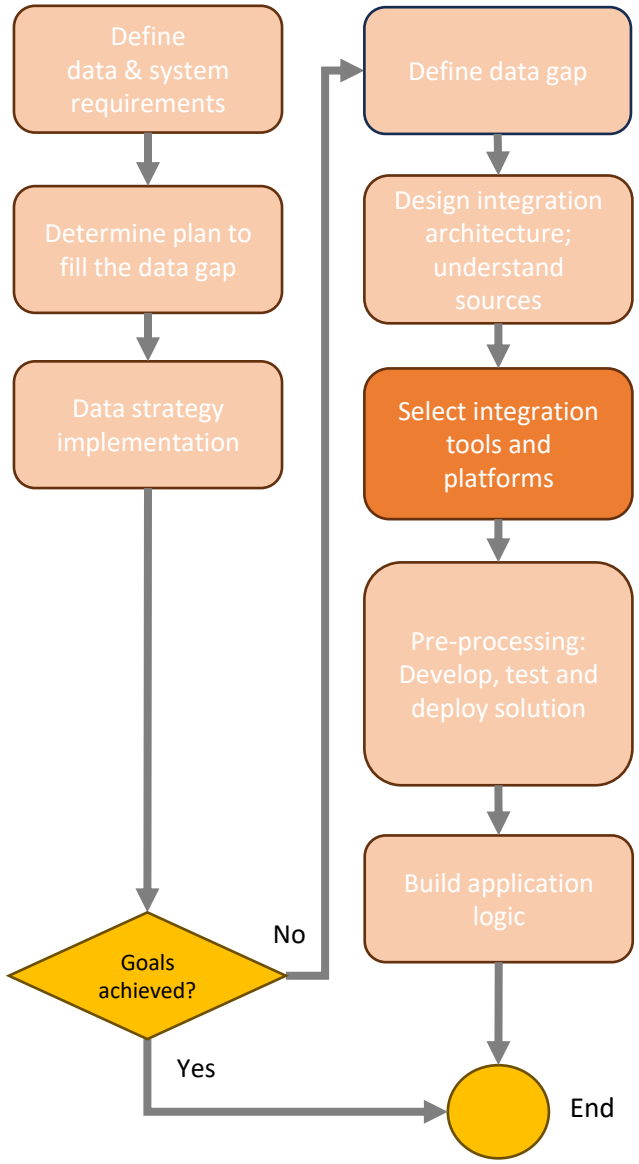
What
A message broker acts as an intermediary for messaging between different systems or software components.

Why
It enables asynchronous communication, ensuring that messages are queued, delivered, and received reliably.

Conditions and requirements
- Scalability
- Performance
- Reliability
- Protocol Support
- Integration Capabilities
- Security

Who needs to do it?
Data engineer

Examples: RabbitMQ, Apache Kafka, MQTT brokers.



Timeseries database

Integrate

What
A time series database is optimized for handling time-stamped or time-series data, such as sensor readings or log data, which is common in BMS.

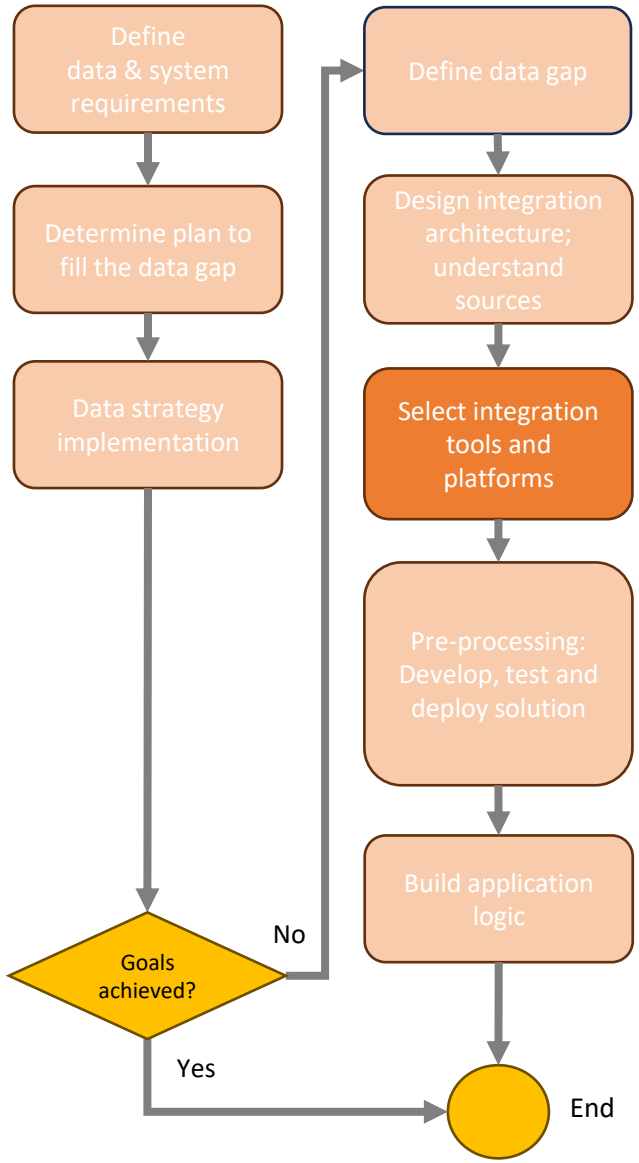
Why
The previously mentioned message brokers get expensive when the datasets get larger over time. A timeseries database is ideal for storing information for longer periods of time.

What are conditions and requirements for its execution?

- Write and Query Performance
- Data Compression and Storage Efficiency
- Scalability
- Data Retention Policies
- Integration with Analytics Tools
- Reliability and High Availability

Who needs to do it?
Database engineer

Examples: InfluxDB, TimescaleDB, Prometheus.



Driver

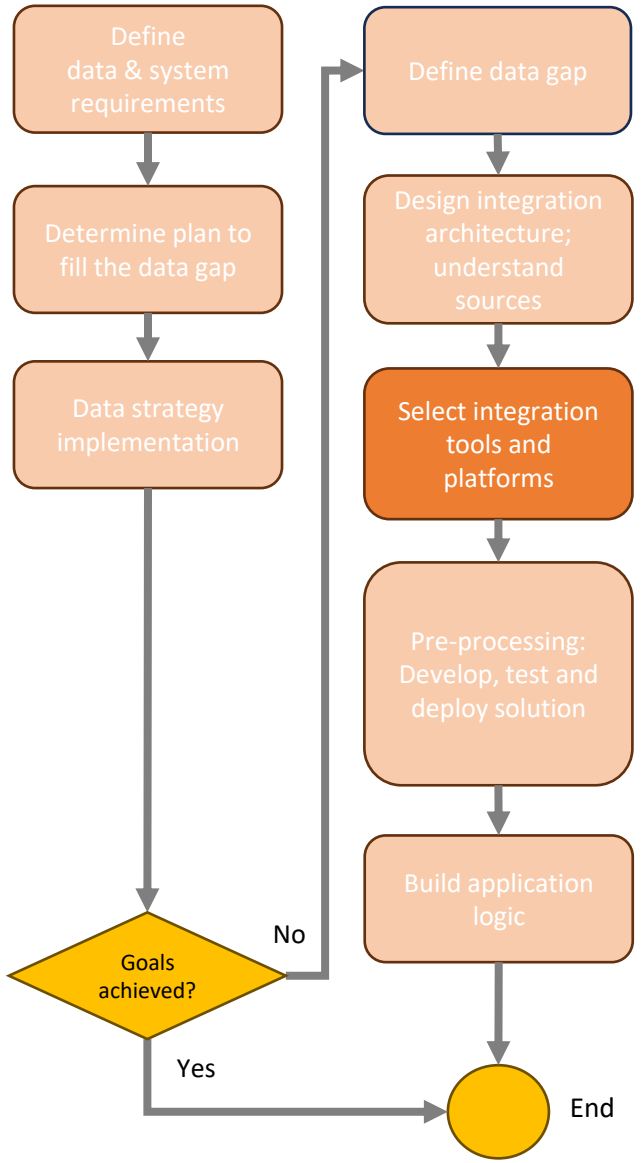
What does this step mean?
A driver in data engineering serves as an intermediary that translates queries and data operations between the application and the data source, ensuring seamless data access and manipulation.

Why do we need it?
- Interoperability
- Abstraction
- Efficiency
- Standardization
- Scalability

What are conditions and requirements for its execution?
- Compatibility
- Network Accessibility
- Resource Availability

Who needs to do it?
Data engineer

Examples: MySQL ODBC Driver, PostgreSQL JDBC Driver, Apache Kafka Connectors



Metadata database

Integrate

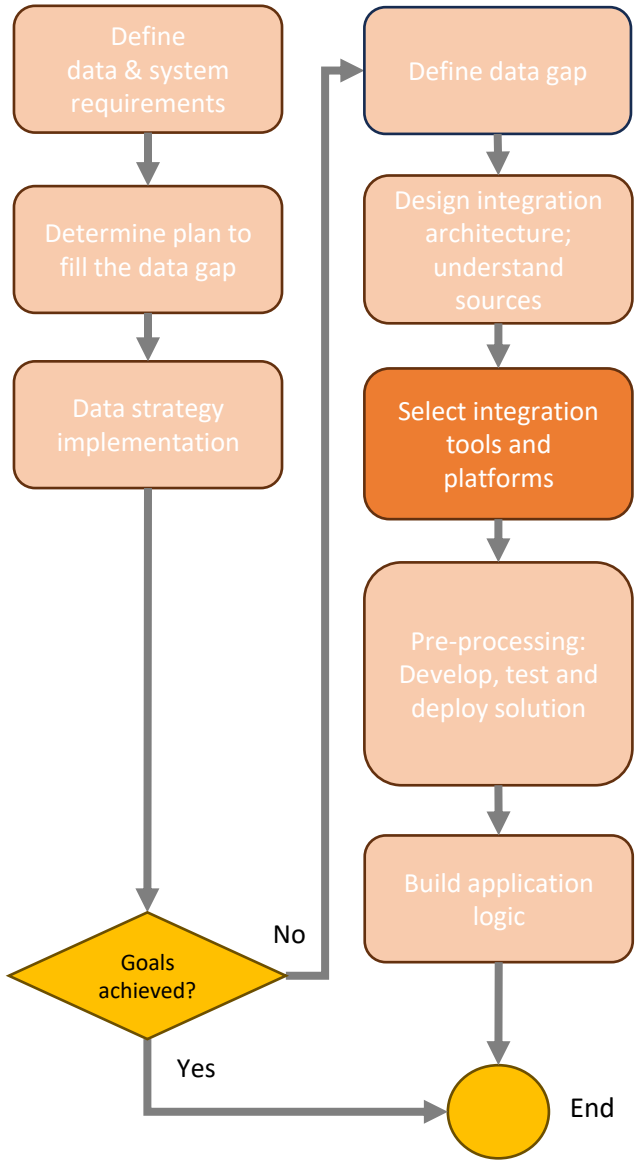
What
A metadata database stores information about other data in the system, such as data source details, schema information, building drawings, and configuration settings.

Why
While a timeseries database is ideal for storing time-stamped data, they are not suited for storing unstructured information. A metadata database is optimized for storing relational information.

Conditions and requirements
- Schema Flexibility
- Query Performance
- Scalability
- Consistency and Reliability
- Interoperability
- Security

Who needs to do it?
Database engineer

Examples: PostgreSQL (with JSONB support), MongoDB, Apache Cassandra.



Pre-processing

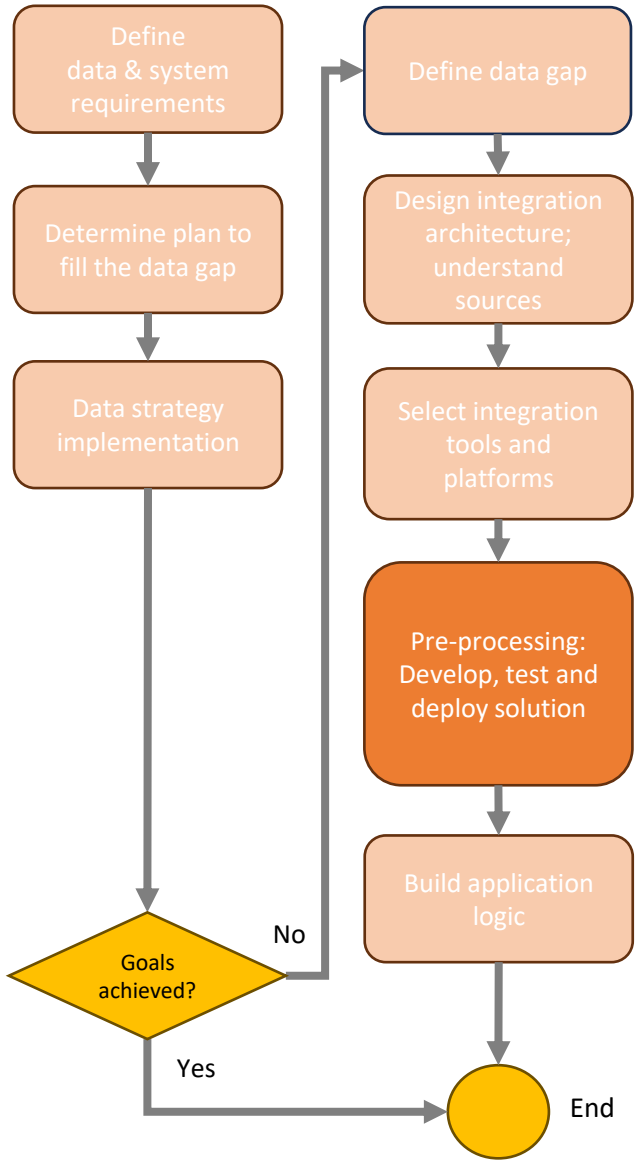
Integrate

What
Before pushing the data to the message broker and database, the data needs to be clean.

Why
Oftentimes, data is not extracted in the required form. The labels are not intuitive, there is missing data, or the measurements are wrong (outliers).

Who
Data engineer with a building- and/or facility manager.

To dive deeper into the preprocessing, see course by Martin WP5



Data labelling

One of the most common problems in smart building applications is inconsistent data labeling.

different vendors and follow different naming conventions.

Different buildings and systems use diverging standards and conventions.

Unstructured naming conventions and tagging systems to represent data syntax and semantics make it difficult to understand and interpret the data.

Data labelling

Example of naming convention in Johnson Controls

TU Delft sensor naming convention
(##) ###.XX-##XX-

- (##) – Building number
- ### – System number
- XX – Control engineering code
- XX- – Reporting, measuring and control code

Name	Description
(28) 201.TA-01A--	Vorstgevaar
(28) 302.VA-01A--	Afzuigventilator storing
(28) 201.VT-01A--	Toevoerventilator storing
(28) 201.CP-01A--	Circulatiepomp verwarmer storing
(28) 201.WW-01A--	Warmtewiel storing
(28) 201.VA-01A--	Afvoerventilator storing
(28) 201.CV-02V--	Regelafsluiter koeler
(28) 201.CV-01V--	Regelafsluiter verwarmer
(28) 201.VT-01B--	Toevoerventilator bedrijf
(28) 302.FT-01M--	Flowmeting LBK2
(28) 302.PT-01M--	Afzuigdrukopnemer
(28) 201.TT-02M--	Retourtemperatuur
(28) 201.PT-01M--	Inblaasdrukopnemer
(28) 201.TT-01M--	Inblaastemperatuur
(28) 201.PT-01M--	Afzuigdrukopnemer
(28) 201.MT-01M--	Inblaasvocht
(28) 302.VA-01B--	Afzuigventilator bedrijf
(28) 201.CD-02SW-	Afblaasluchtklep west vrijg.
(28) 201.CD-02SO-	Afblaasluchtklep oost vrijg.
(28) 302.VA-01S--	Afzuigventilato vrijgave
(28) 201.VT-01S--	Toevoerventilator vrijgave
(28) 201.CP-01S--	Circulatiepomp verwarmer vrijg.
(28) 201.WW-01S--	Warmtewiel vrijgave
(28) 201.VA-01S--	Afvoerventilator vrijgave
(28) 201.CP-01B--	Circulatiepomp verwarmer bedrijf
(28) 201.WW-01B--	Warmtewiel bedrijf
(28) 201.VA-01B--	Afvoerventilator bedrijf
(28) 201.WW-01V--	Warmtewiel sturing
(28) 302.VA-01V--	Afzuigventilator sturing
(28) 201.VT-01V--	Toevoervent. sturing
(28) 201.VA-01V--	Afvoervent. sturing
(28) 201.SC-03M--	Signaal toerenreg. VA
(28) 201.SC-02M--	Signaal toerenreg. VA
(28) 201.SC-01M--	Signaal toerenreg. VT
(28) 201.TT-03M--	Aanzuigtemperatuur
(28) 201.TT-07M--	Retourtemp. verwarmer
(28) 201.TT-05M--	Inblaastemp. na ww
(28) 201.TT-04M--	Afblaastemp. na ww
(28) 201.PDT03M--	Drukverschil 1e filter
(28) 201.PDT04M--	Drukverschil 2e filter
(28) 302.CD-01V--	Luchtklep sturing

Building number:
Building 28

System number:
201 = AHU

Control engineering code:
CV = Control valve

Process number

Reporting, measuring and control code:
M--: measurement

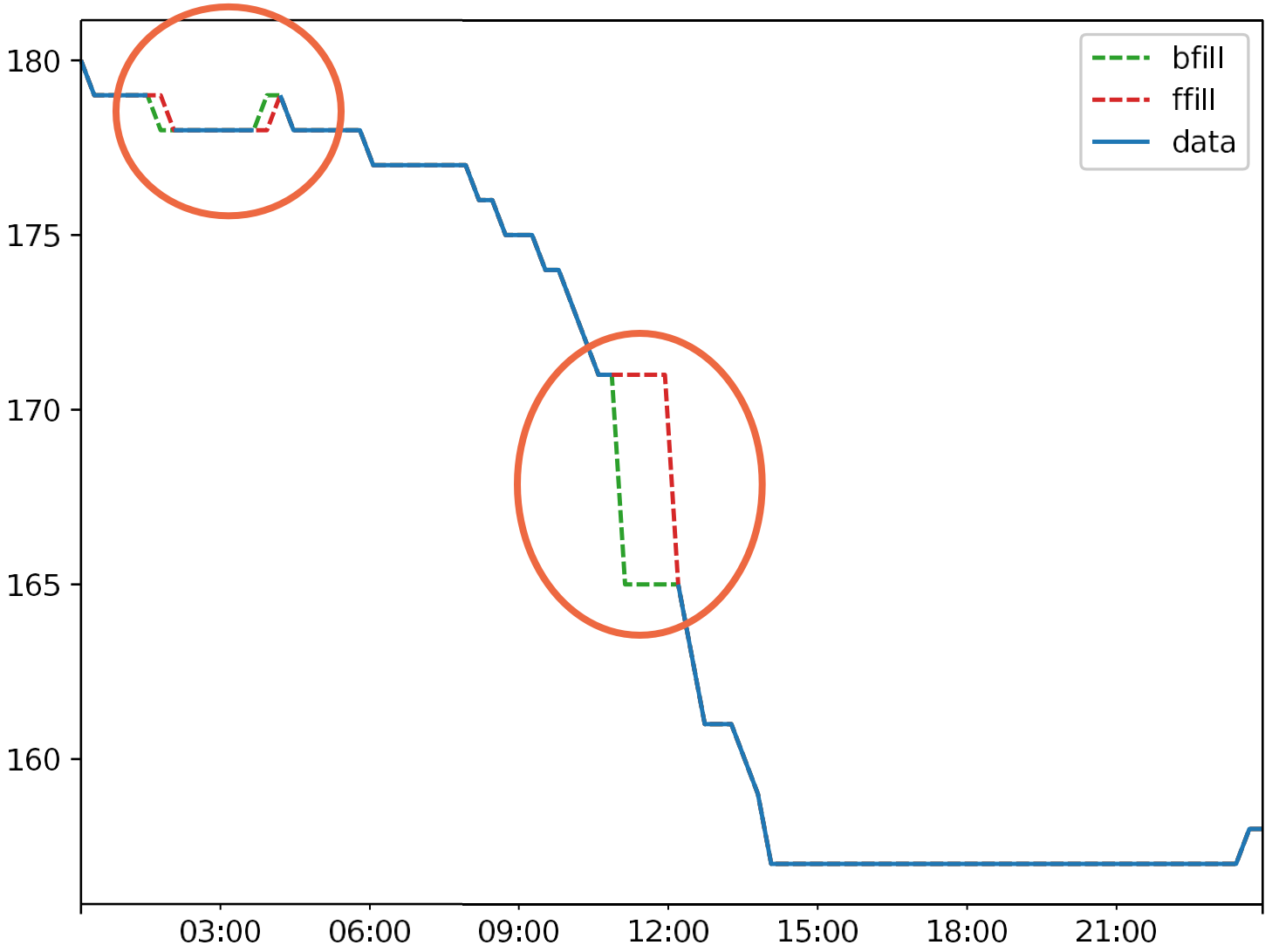
A--	Alarm
B--	Bedrijfsmelding
D--	Dicht
HS--	Hoofdschakelaar
L--	Lokaal bediend
LG--	Lichtgroep
M--	Meting
O--	Open
S--	Schakelen
T--	Telling(er)
V--	Sturing
WS-	Werkschakelaar
W--	Werksetpunt
X--	Instelling (X-as)
XS-	Setpunt verstelling
Y--	Instelling (Y-as)

	sturingen
SU-	urgente storing
SN-	niet urgente storingsmelding
SR-	reset op afstand (GBS)
SB-	brandsturing
SI-	brandschakelaar ventilatie in
SU-	brandschakelaar ventilatie uit
SS-	staffel relais
SRP	resetplus
	meldingen
BR-	reset storing
BI-	herinschakelen ventilatie na brand
BU-	heruitschakelen ventilatie na brand
BV-	voeding aanwezig
L--	regelkast lokaal bediend
BS-	spanningsbewaking stuurstroom (NC)
	alarmen
AB-	brandmelding RK-01 BMC
AN-	netwachter
AS-	sabotage
AI-	installatie automaten

Missing data

Techniques used for treating erroneous and missing values vary from one application to another:

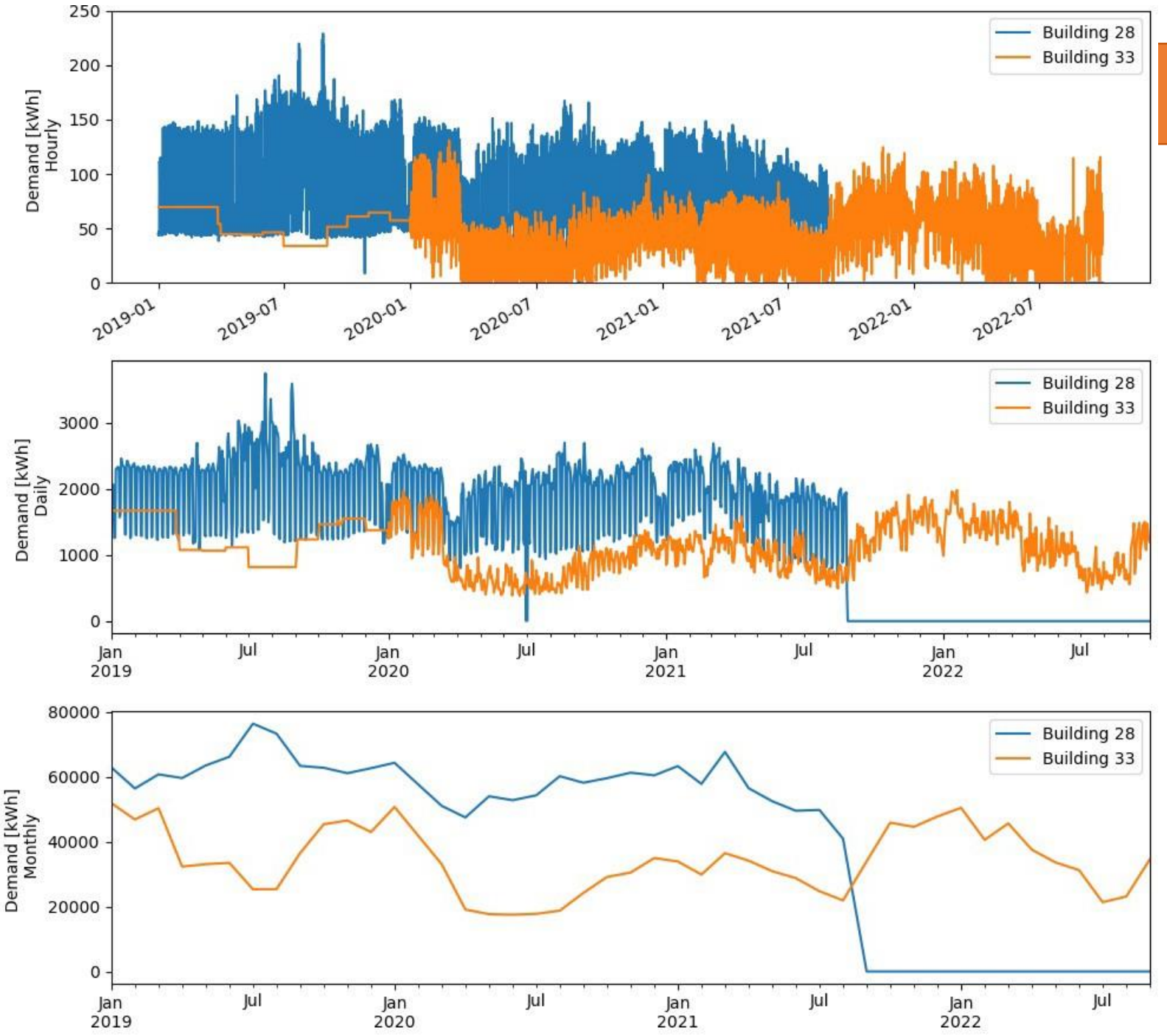
- replacing with next or previous value
- Interpolation
- Rolling average



Downsampling

When gathering frequency does not match the intended application

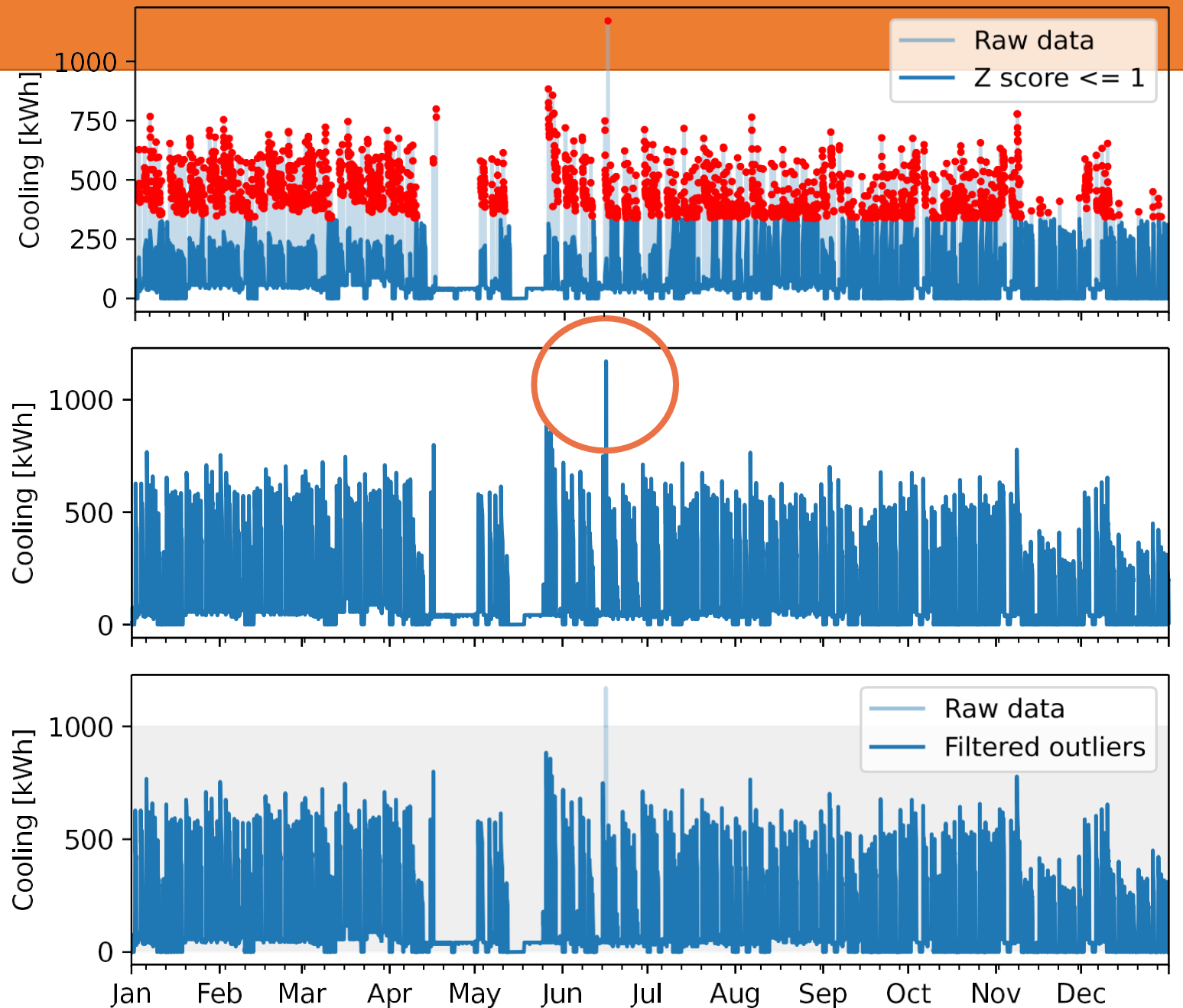
- Choice of frequency: hourly, daily, monthly, etc.
- Choice of down sampling method
  - Mean: e.g., operating temperature, pressure
  - Sum: e.g., energy demand



Outliers

Removing unexpected outliers to ensure they do not influence the intended application:

- expected range of values (if available)
- Z-scores: need to pick a reasonable value

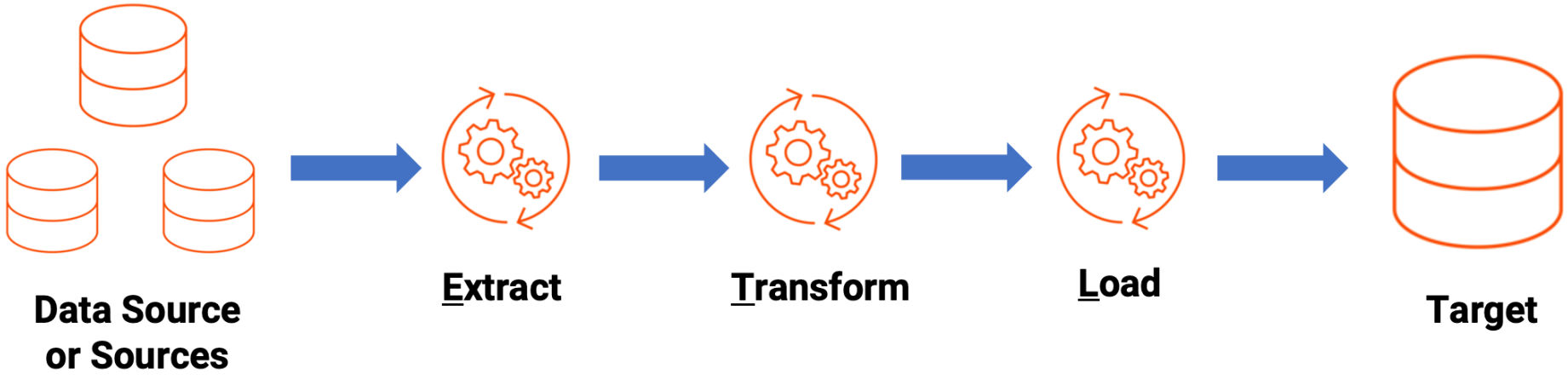


Integration

What
When the data preprocessing is finished, it can finally be integrated. The data can be pushed to the message broker, which will in turn store the data in the database.

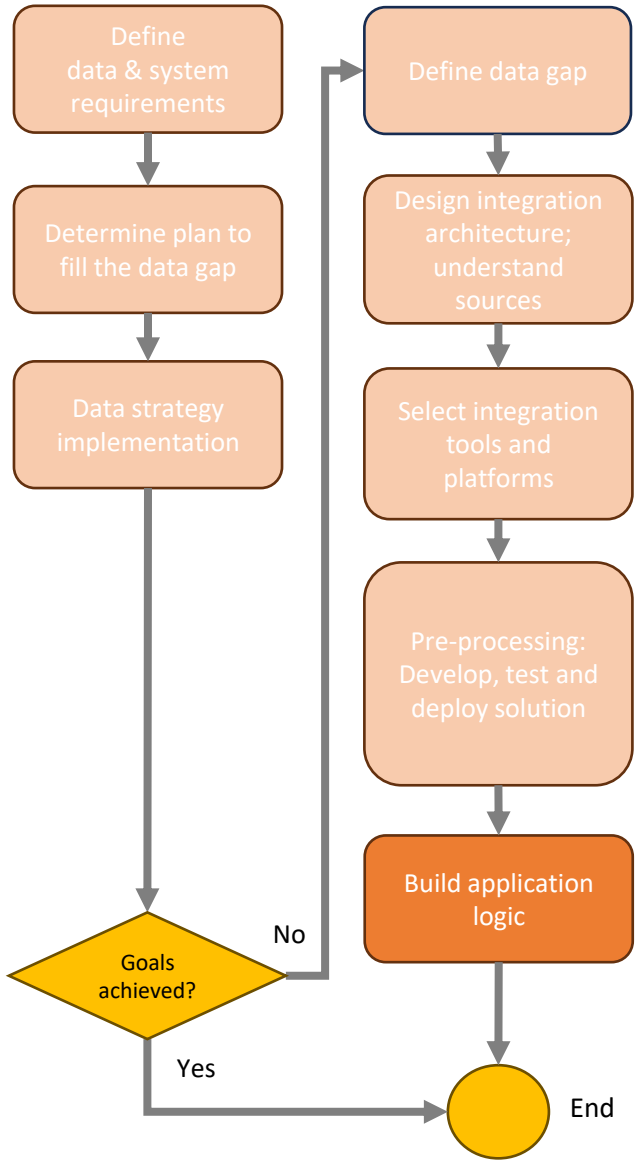
Conditions and requirements
The tools like the message broker, and database need to be in place. Furthermore, the previously mentioned preprocessing needs to be performed on the data to have a proper Extract Transform and Load (ETL) pipeline.

Who needs to do it?
Data engineer



Build application logic

Integrate



This Roadmap is a part of the Brains for Buildings (B4B) project. This is a multi-year, multi-stakeholder project that aims to develop smart building methods to enhance operations in buildings by reducing energy consumption, increasing energy flexibility, increasing occupant comfort, and improving installation maintenance costs. This will be achieved by developing faster and more efficient Machine Learning and Artificial Intelligence models and algorithms. The project is geared towards existing utility buildings, such as commercial and institutional buildings.

The Brains4Buildings is sponsored by the Dutch grant program for Mission-Driven Research, Development and Innovation (MOOI). This program was established by the Dutch Ministry of Economic Affairs and Climate Change and the Ministry of the Interior and Kingdom Relations and executed by RVO Netherlands Enterprise Agency.