Designing a digital twin for a ski resort

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Table of contents

Context of digital twins

A digital twin is a virtual representation of a physical system that is used to simulate and analyze the system's behavior.

Characteristics of a digital twin:

- It is a virtual representation of a physical system
- It completely describes the system across its entire lifecycle
- It is typically used as a decision support tool
- It can be linked to the physical system for a real-time interaction

Utility of digital twins in the ski resort

A digital twin is usefull because:

- it can be usefull for mantainainte scheduling and implementation
- it can be used for optimising and scaling the system
- it can be usefull to extract insight from the system

A digital twin for a ski resort

- The ski resort is a complex system with many components
- The energy system is mainly impacted by the skiers behaviour
- The comfort of skiers (via the quality of service) must be taken into account

To design such a virtual system, we neet to apply a model based system engineering approach.

Model based system engineering

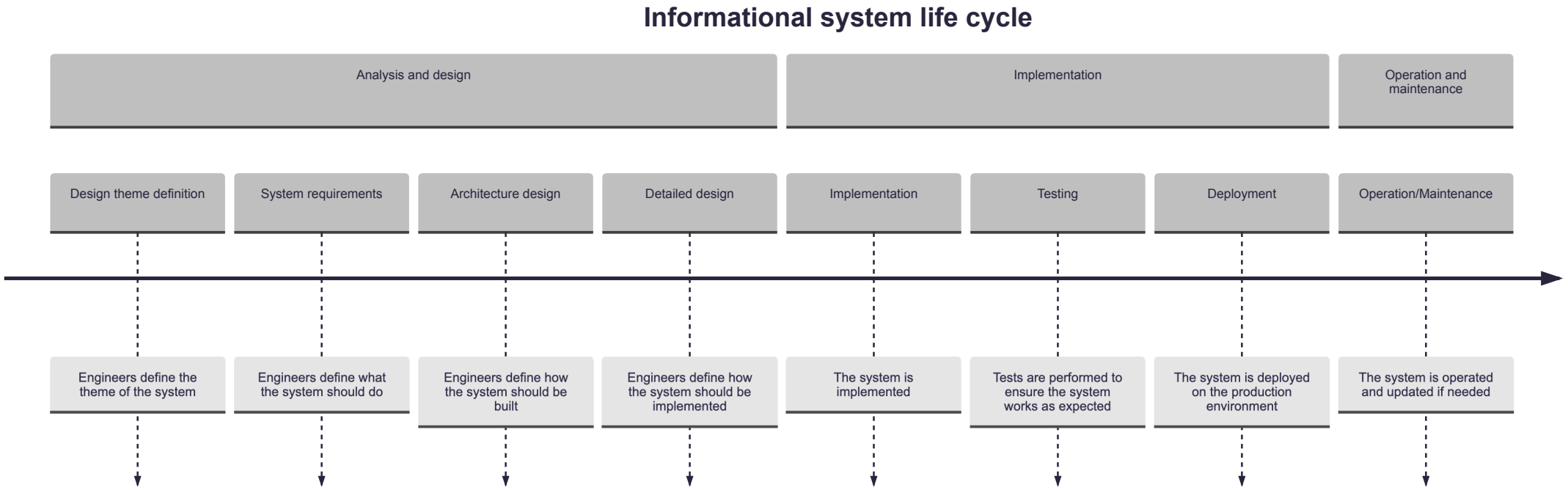
Informational systems

A technical system is an ansamble of tehnical components interacting with each other to achieve a specific goal.

An informational system is a system that is composed of hardware and software components, used to collect, store, and process information for a specific purpose.

Can a digital twin be considered as an informational system?

Designing informational systems



System engineering

A system requirement is a statement of what the system should do to satisfy a specific need.

A system engineer is a person who is responsible for managing the system requirements.

More specifically, a system engineer is responsible for:

- Defining the system requirements
- Ensuring that the system requirements are met
- Ensuring that the system is implemented correctly and follows the design

System design and analysis

System design and analysis is the process of creating a model of a system to understand its behavior and how users interact with it before its implementation.

Benefits of system design and analysis:

- It helps reducing the resources for implementation
- It helps to identify potential issues and risks
- It helps to desing a system that is perfectly suited for the users

The objective in the digital twin context

We must do the analysis and design for a digital twin of a ski resort.

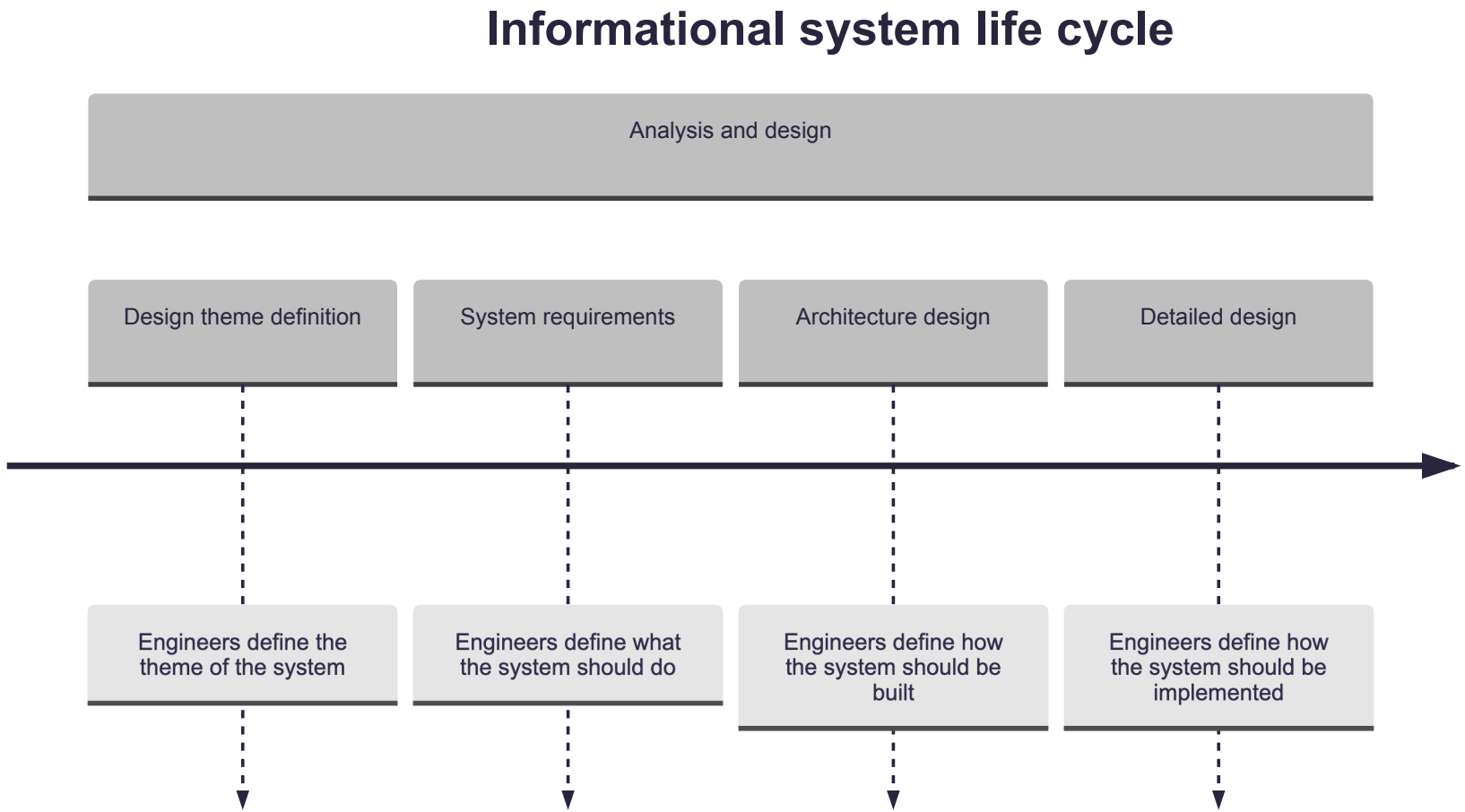
- We will start by understanging what are the tools that we can use.
- We have to design the system requirements (and possibly a system architecture)
- We will follow an example on an information system for an energy community as a starting point.

SysML

SysML (System Modelling Language) is a standard for modeling systems from a system engineering perspective.

- SysML is an extension of UML (Unified Modeling Language), which is rather used for software engineering.
- It consists of diagrams (models) to describe different aspects of the system.
- The diagrams are used because of the ease of use, their mantainability and their ability to represent complex systems.

System analysis stages



Design objective

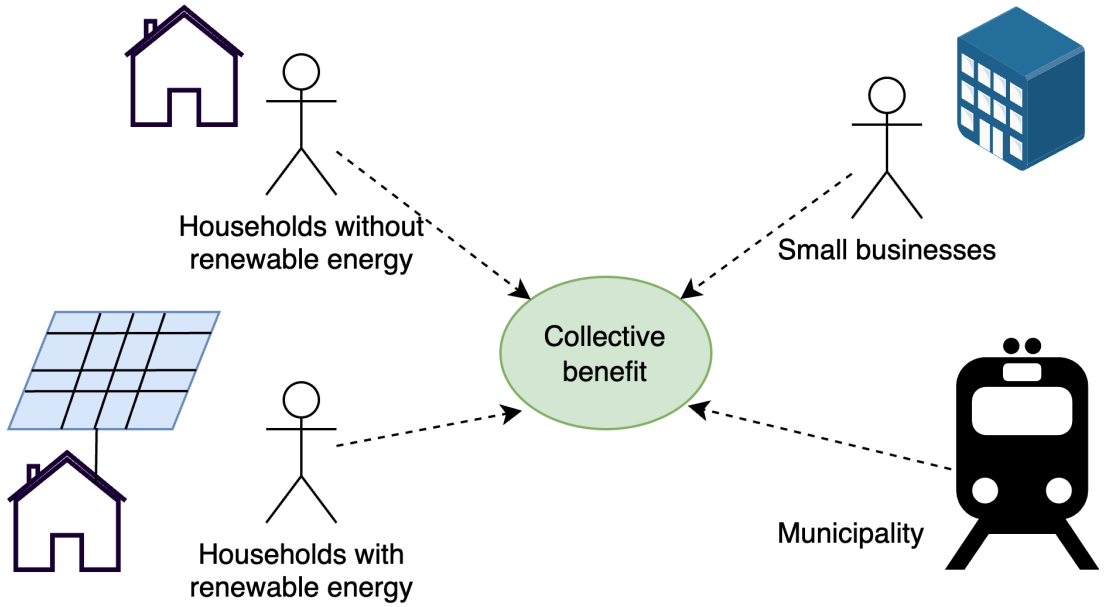
The design objective must describe the scope of the system.

it should breifly describe the stakeholders, possibly the main actors and the main goals.

The scope of the system is typically associated to a problem that must be solved.

Example: desinging an informational system for an energy community

Energy community - a group of people/small to medium enterprises/local authorities who voluntarily participate in democratic energy sharing mechanisms to obtain a certain environmenal/social/economic benefit.



- people - individuals who want to contribute towards a common goal (with or without production capabilities)
- small to medium enterprises - shops, restaurants, small offices, etc.
- local authorities - public institutions/transportation companies/etc.

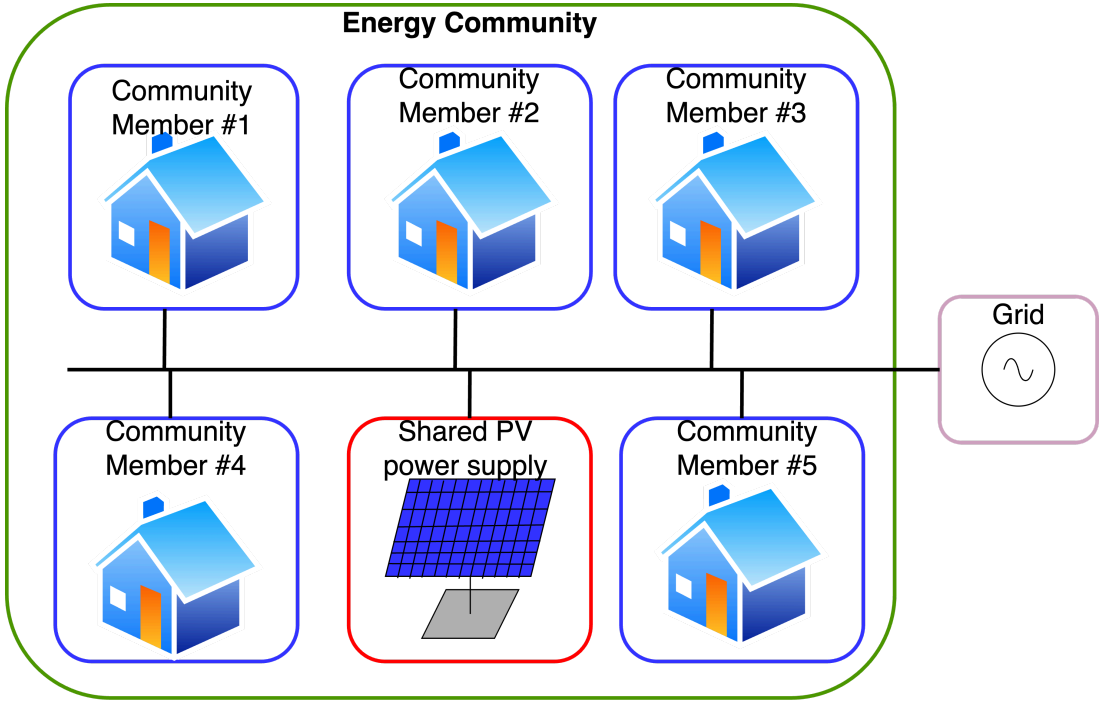
Why not large enterprises?

Example: the design objective for an energy community

- How would the energy sharing mechansim work in a community?
- How would the benefits be distributed among the participants?
- How do we quantify the benefits? Reduction in the bill?
- How do we make the members more aware of the energy consumption?
- How to make the members more engaged towards obtaining the benefits?

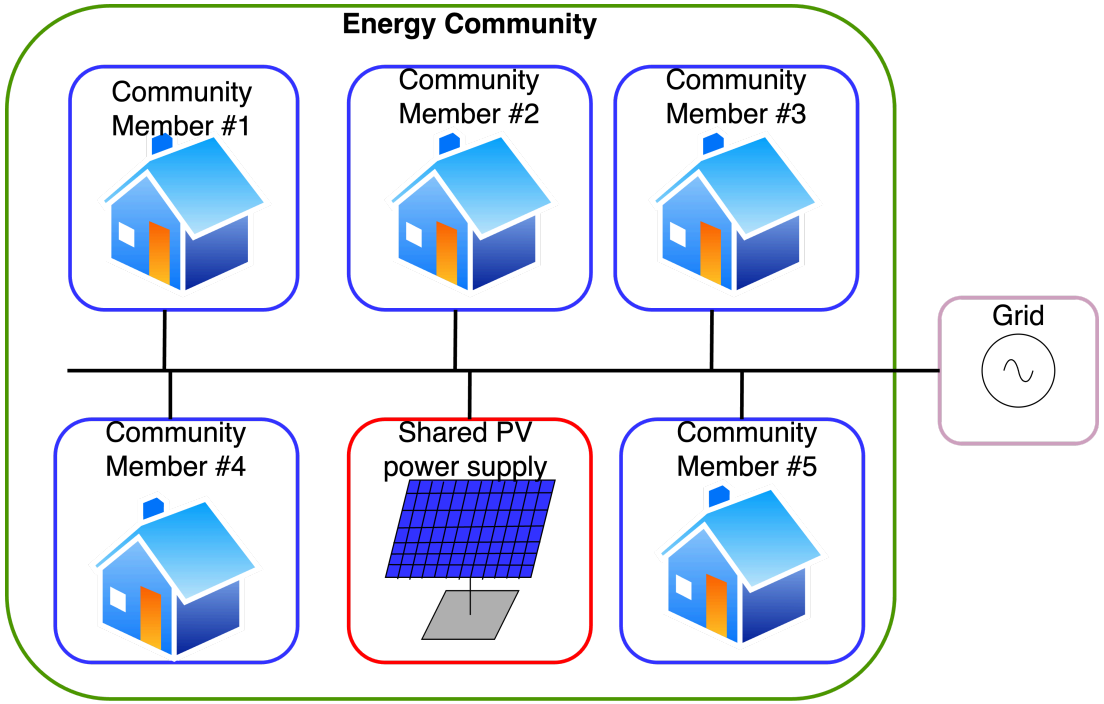
Example: the physical system of an energy community

- Let's consider a residential community formed of households $\mathcal{H} = \{h_1, h_2, \ldots, h_H\}$ where H is the total number of households
- It can be:
  - a neighborhood
  - a set of households in different parts of the city
  - apartments in a building



Example: measurment devices in an energy community

- Each household is equiped with smart meters, measuring the power consumption $P_i(t)$ of the house at the time t
- We consider they share the power of a physical PV plant, generating power $P_{\mathrm{PV}}(t)$
- The houses decide to share the power of the PV plant and togather to act as a single entity

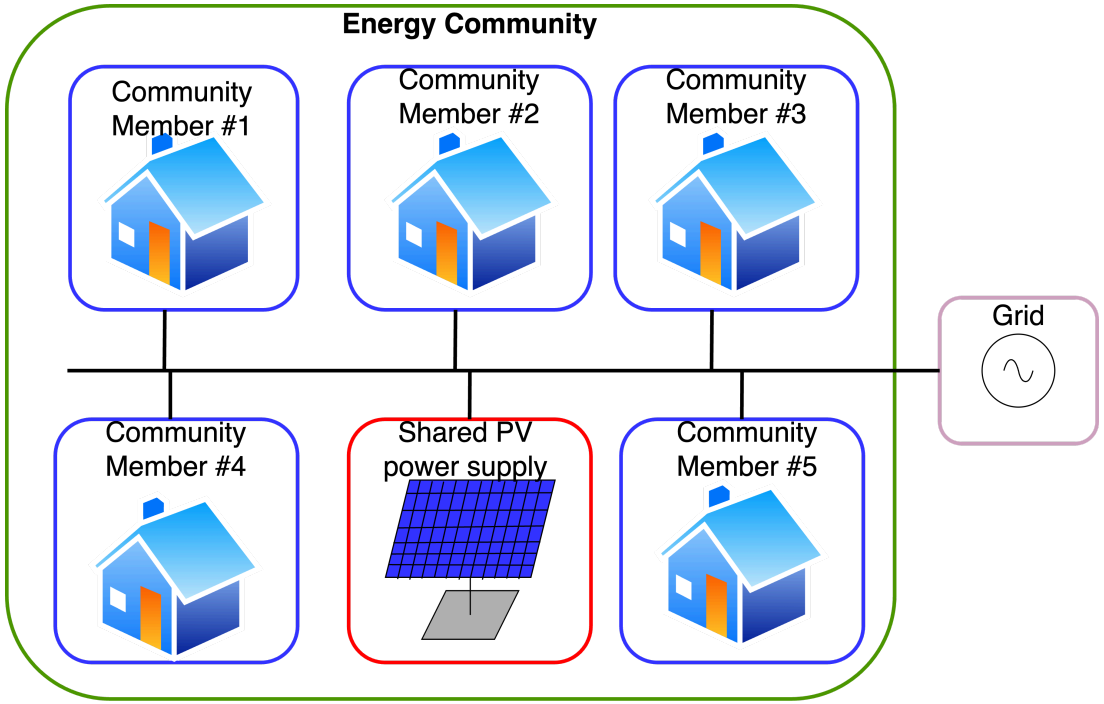


Therefore, the total power consumption $P_{\mathrm{comm}}(t)$ of the community is given by:

$$P_{\mathrm{comm}}(t) = \sum_{i=1}^{H} P_i(t)$$

Example: energy balance in an energy community

- The power produced by the PV plant is characterised by uncertainty.
- At some points, it can be higher than the power consumption of the community (summer, for example).
- At other points, it can be lower than the power consumption of the community (winter or at night).



The energy balance in function of the power extracted from the grid $P_{\text{extract, grid}}(t)$ and the power injected into the grid $P_{\text{inject, grid}}(t)$ is given by:

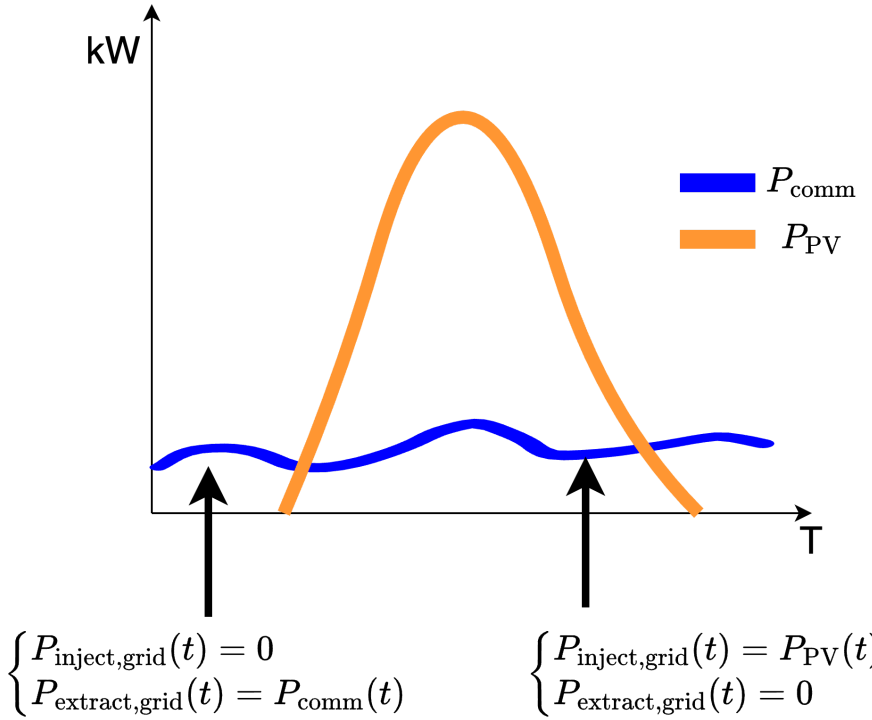
$$P_{\text{comm}}(t) = P_{\text{PV}}(t) + P_{\text{extract, grid}}(t) - P_{\text{inject, grid}}(t)$$

Example: energy balance in an energy community

Let's investigate the energy balance.

$$P_{\text{comm}}(t) = P_{\text{PV}}(t) + P_{\text{extract, grid}}(t) - P_{\text{inject, grid}}(t)$$

- The consumption of the community $P_{\text{comm}}(t)$ at a time t is known.
- The production of the PV plant $P_{\text{PV}}(t)$ at a time t is known.
- The power extracted from the grid $P_{\text{extract, grid}}(t)$ and the power injected into the grid $P_{\text{inject, grid}}(t)$ are determined by the energy balance.



Example: a summer day with high PV production

User types in the interaction with the information system

- Stakeholder: a person/group of people who have an interest in the system
- End user: a person who uses the system to achieve a goal
- System user: a person who uses the system to achieve a goal, but needs additional training to use it

Design objective for an informational system of an energy community

- The information system can be used as a recommendation tool
- It can moniotr the consumption of the community and provide indications to the members
- The indication would be used to increase the efficiency of the community and obtain economic/environmental/social benefits
- The main stakholders are the members of the community.

Can there be other stakeholders?

Example: user types in the interaction with the information system of an energy community

Stakeholder:

- The members of the community
- The local authorities
- The energy provider

End user:

- The members of the community

System user:

- Designated members of the community

The use-case diagram

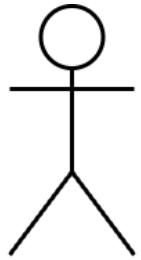
> The use-case diagram is a diagram that shows the interactions between the users and the system.

An interaction must always involve at least an actor (user) and the system or other systems.

Use case elements: the actor

An actor (user) is a person or a group of people interacting with the system.

- The actor deifintion contains typically a short description of the actor, possibly a name.
- The actor is associated with a typical user of the system (end user, system user).

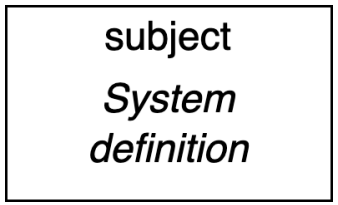


Actor definition

Use case elements: the subject

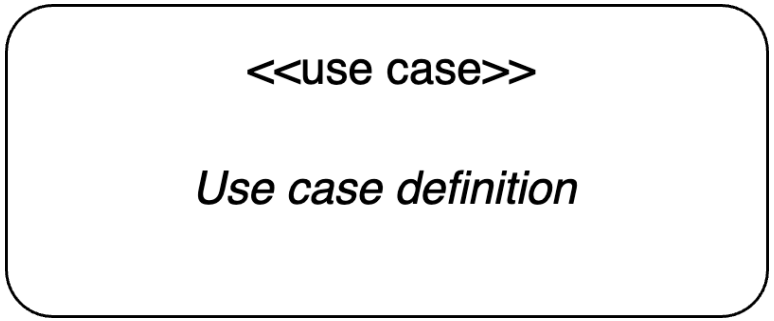
The the subject typically represents the system the user is interacting with.

- It can be the informational system itself, or another system.



Use case elements: the use case defition

The use case definition contains a short description of the use case.

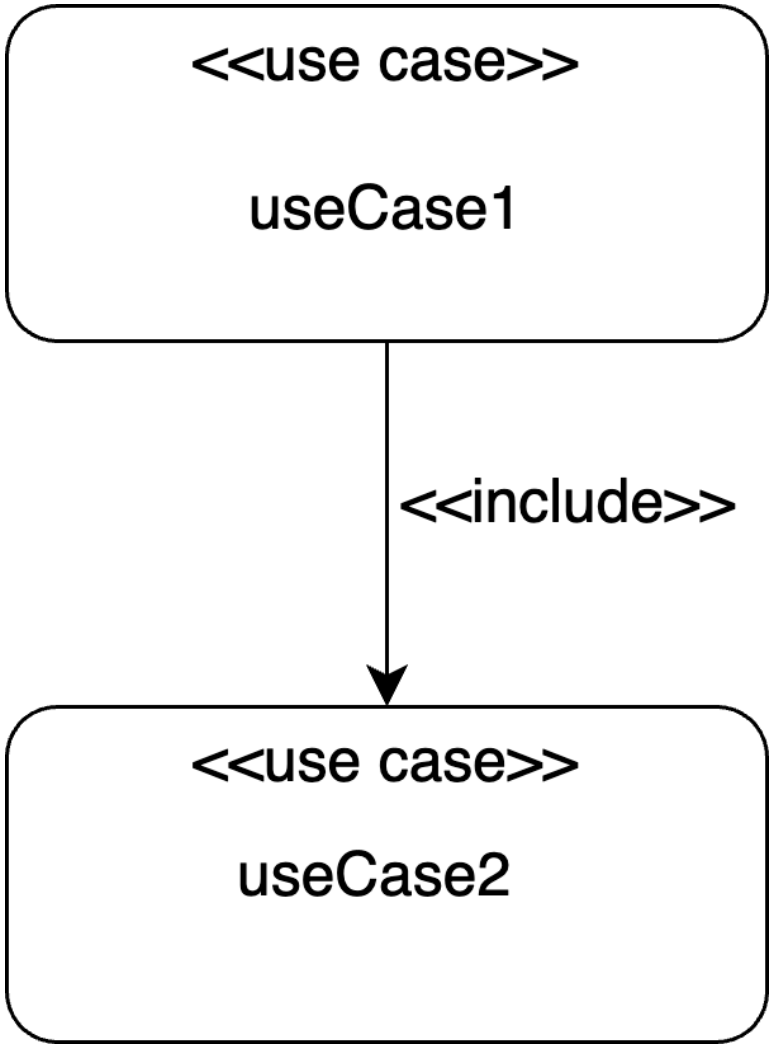


- It is associated with lines "---" to the actor(s) involved and the subject.
- There must be at least an actor associated.
- There must be at least one subject associated.
- It should not include time dependencies.

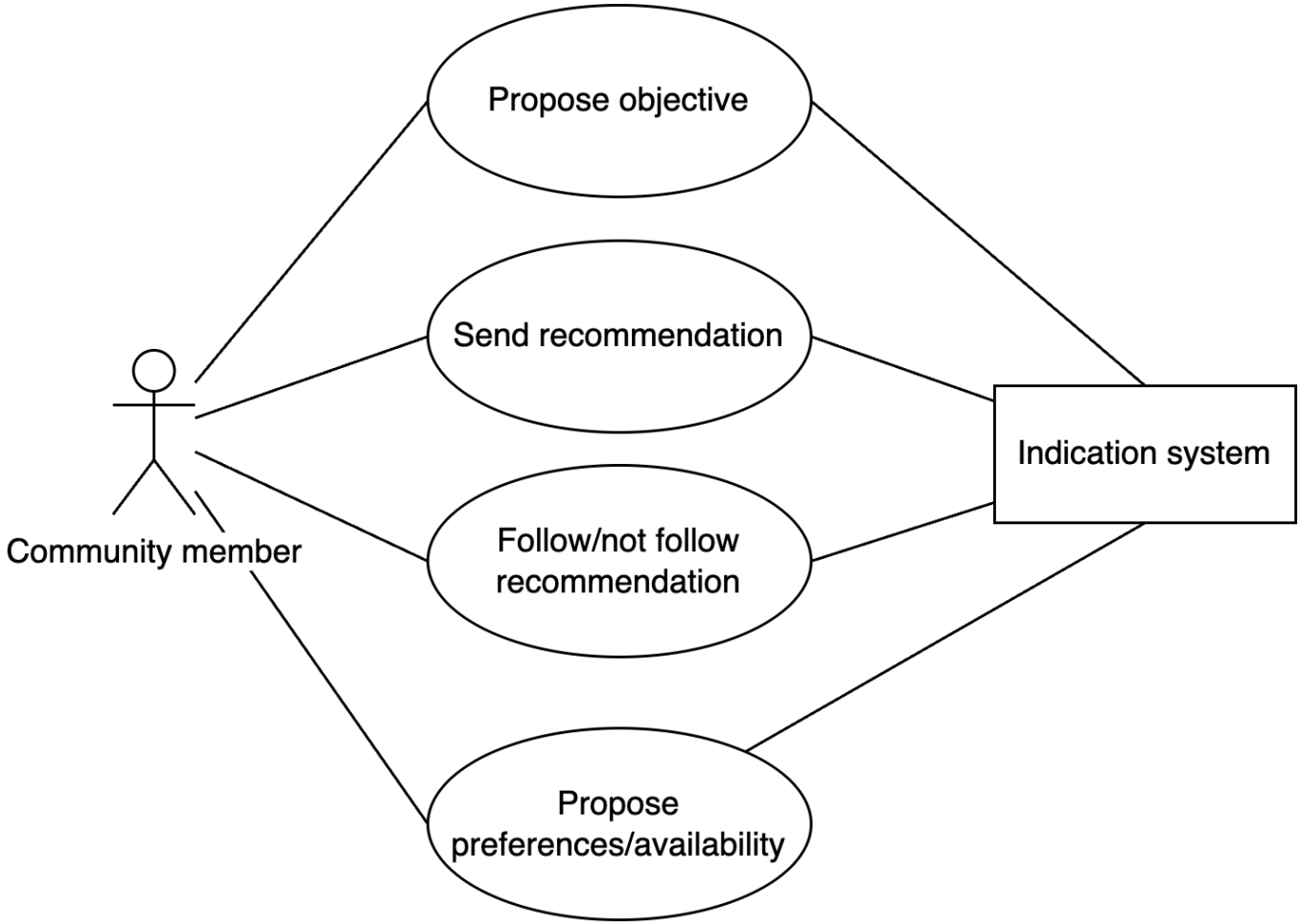
Use case elements: the inclusion relationship

The inclusion relationship is used to represent a use case that is included in another use case.

- It is used to explain more complex relationships.
- It is not mandatory to use this relationship. A simple, descriptive diagram is usually enough.



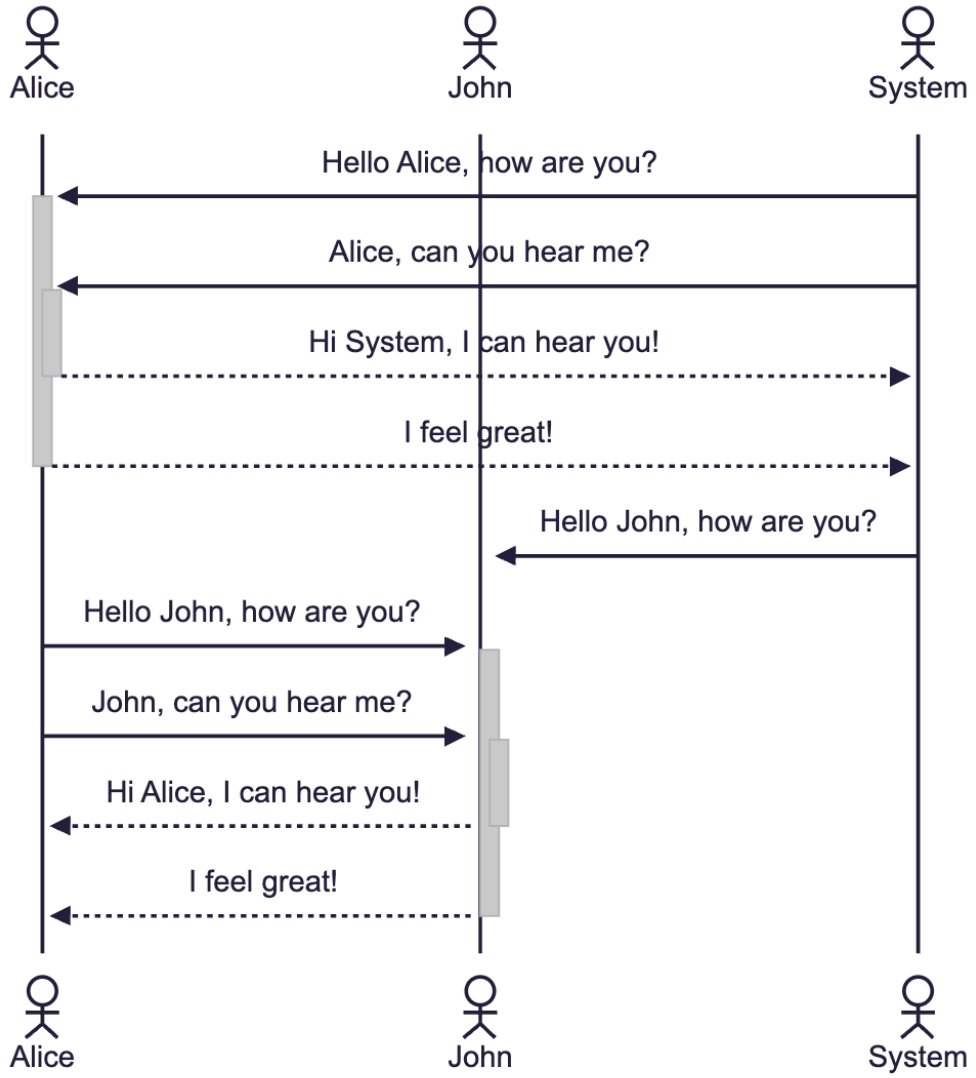
Energy community use case diagram



Sequence diagram

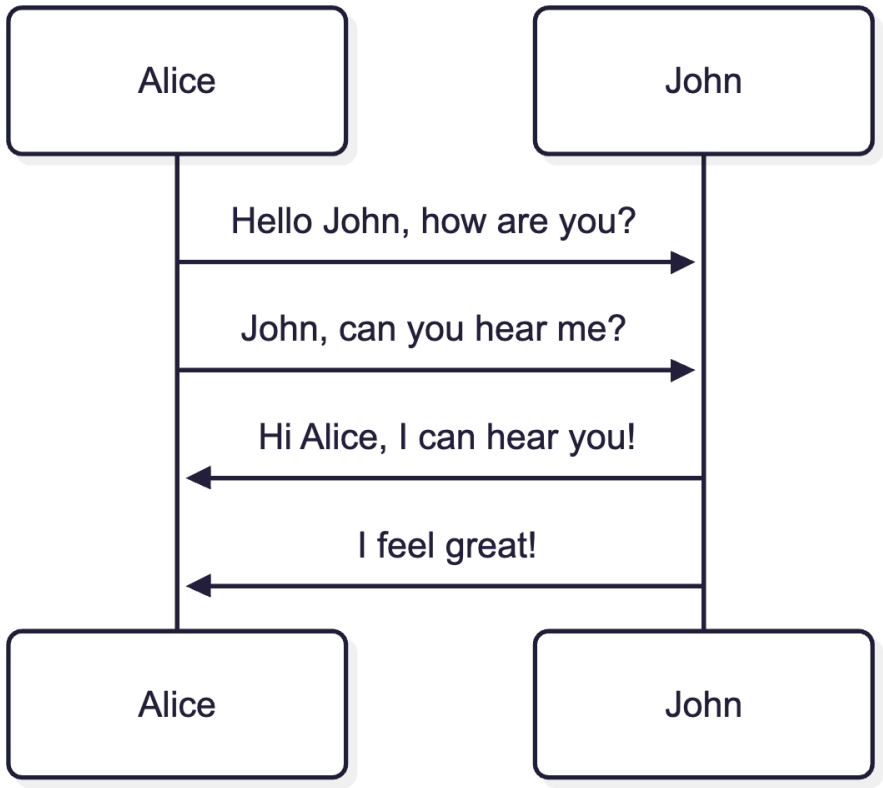
The sequence diagram is a diagram that shows the interactions between the users and the system in a time-based manner.

- The same rules regarding interaction componenets (users/systems) still apply.
- The difference appearing is the time line emerging from each actor.
- Each use case has an associated sequence diagram.



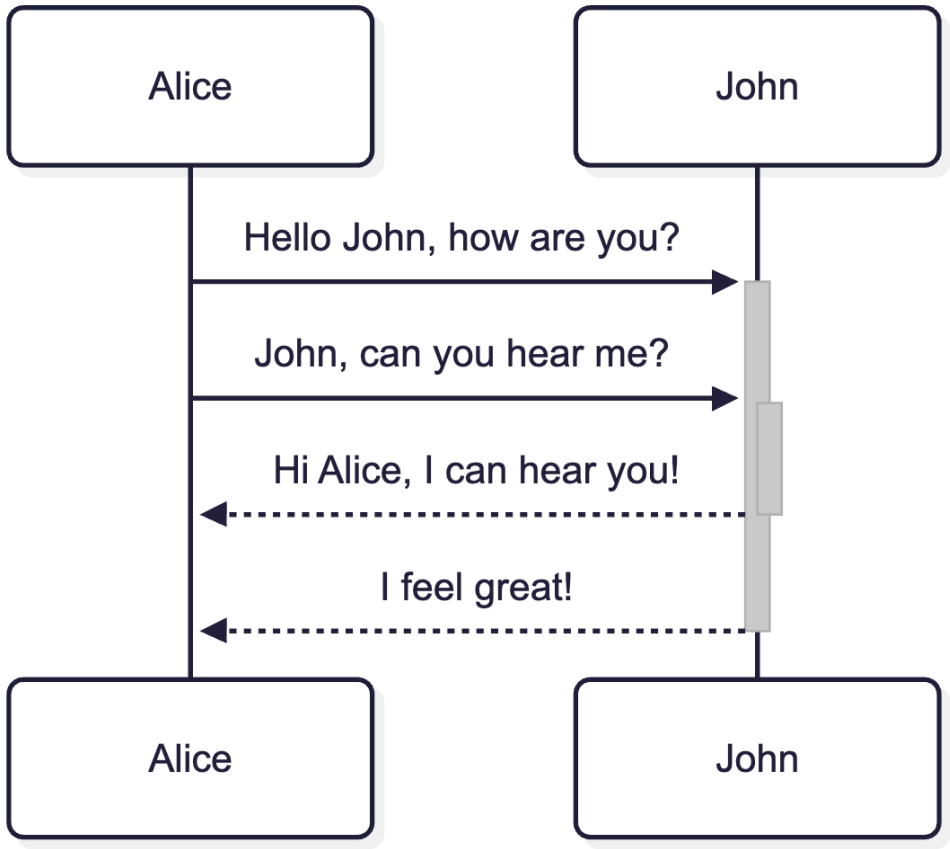
Sequence diagram - basic messages

- Actors can send messages to each other.
- The messages are represented by arrows.
- There is no dependency between the messages.



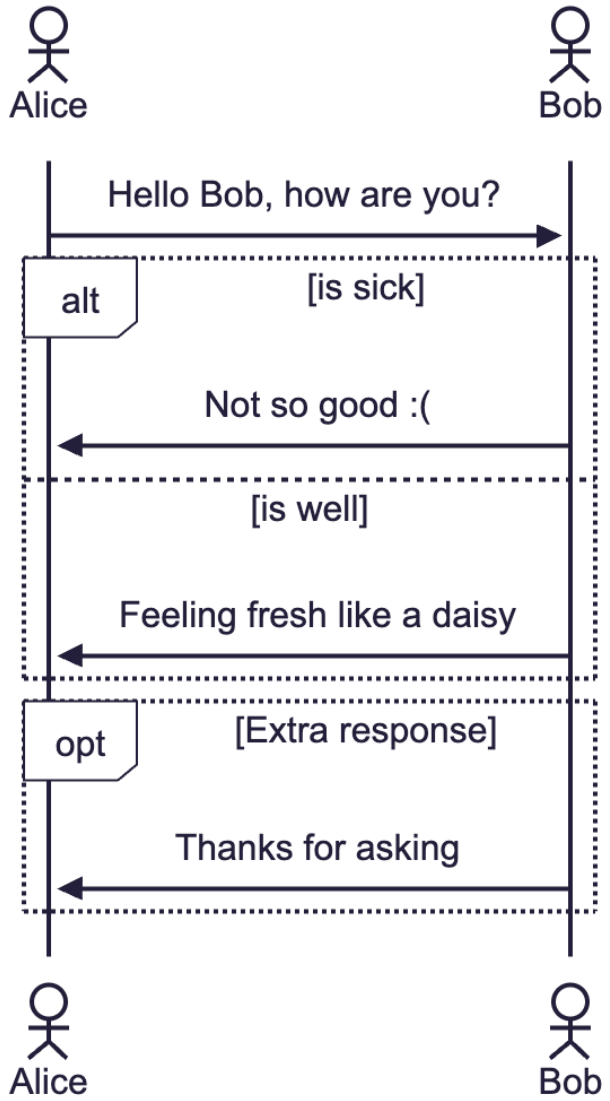
Sequence diagram - activation

- Actors can send messages, with a requirement to respond.
- This prompts the other actor to activate itself.
- At the end of the activation, the other actor sends a message to the first actor, marked with a dashed line.



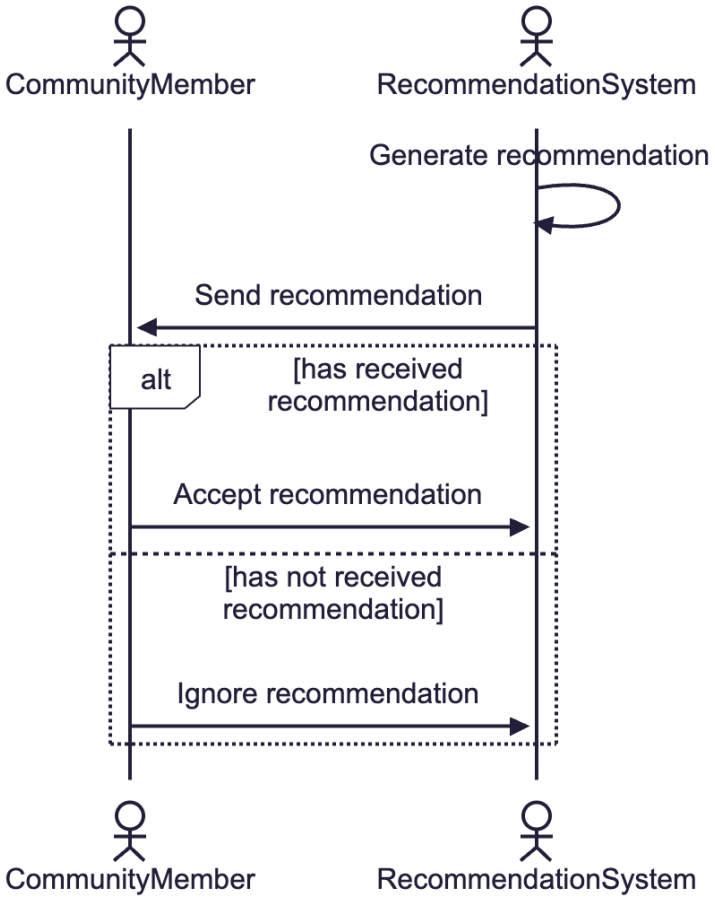
Sequence diagram - if-else

- The messages can be conditional.
- It mimics the if-else structure of the code.
- The other actor can choose to respond or not.

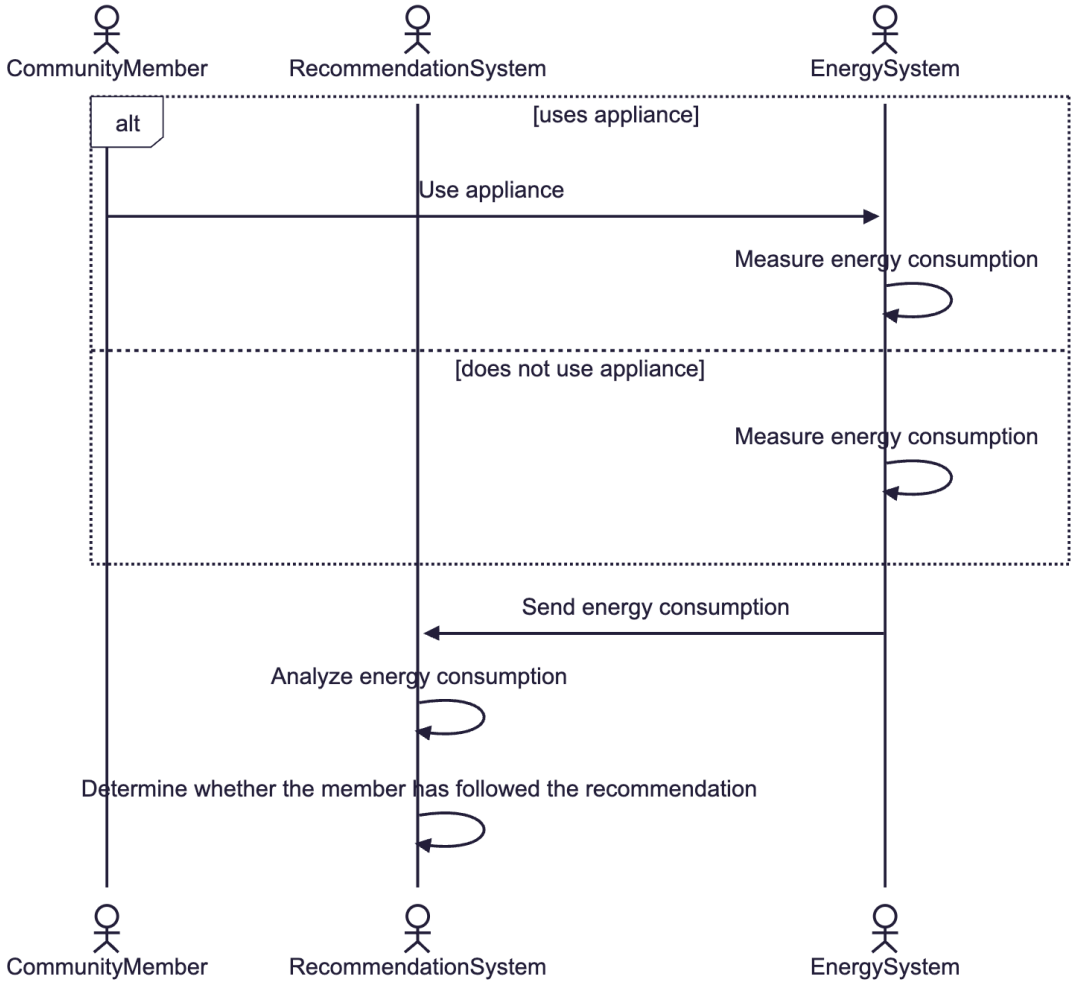


Energy community sequence diagram

Use case - send recommendation



Use case - react to recommendation



Requirements diagram

> The requirements diagram is a diagram that shows the requirements of the system.

A requirement is a statement of what the system should do to satisfy a specific need.

Requirements are defined based on sequuence diagram, looking from the perspective of the system.

They typically follow the following structure:

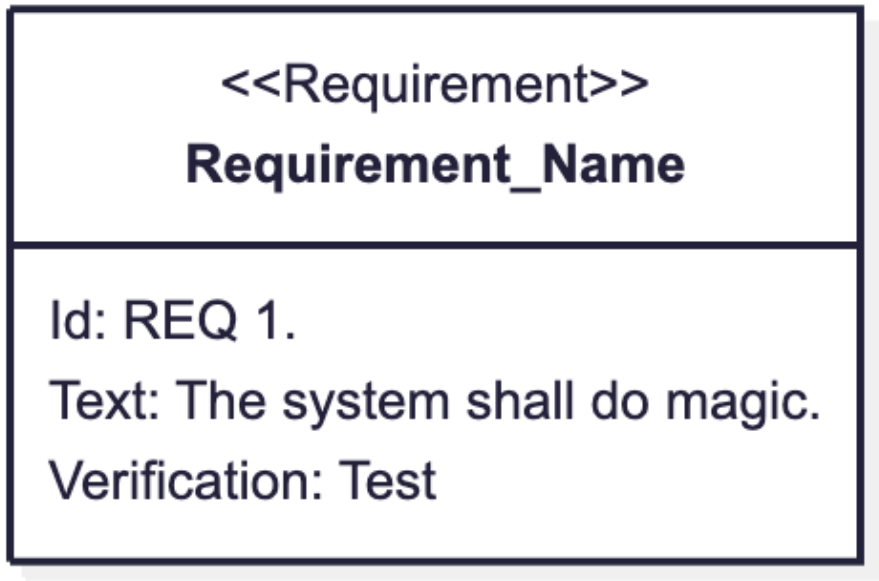
- The system must be able to ...
- Requirements must be verifiable and, thus, measurable.

Requirements diagram - basic requirement

A requirement has also an id, for better structuring.

The text of the requirement defines shortly what the system should do.

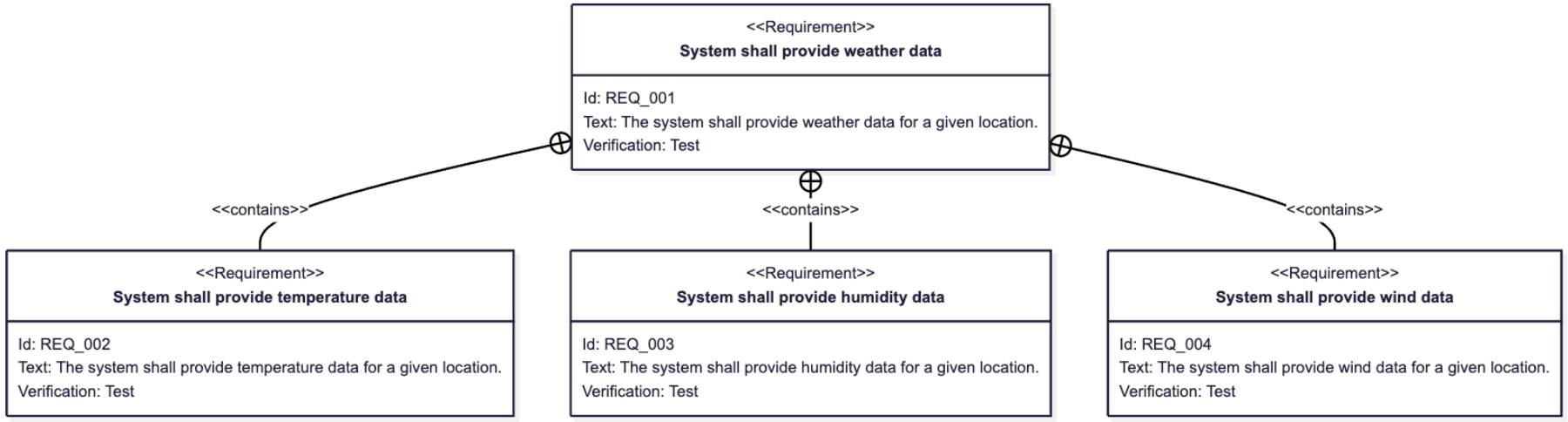
If available, a test can be associated to the requirement.



Requirements diagram - the composition relationship

Requirements diagram allow us to compose requirements.

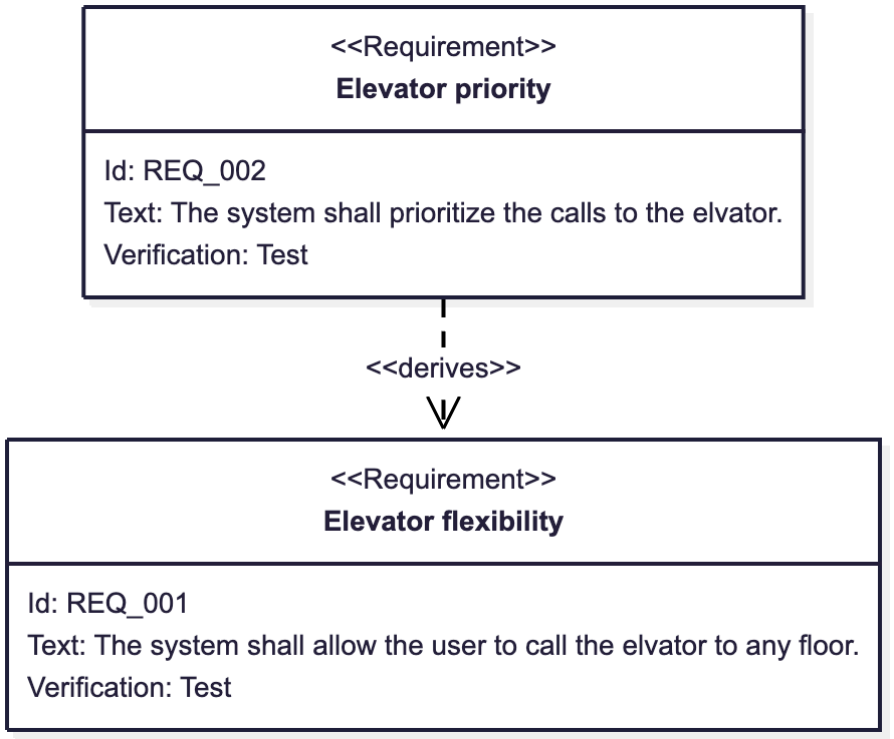
A composed requirement is a requirement that can only be satisfied if the component requirements are satisfied.



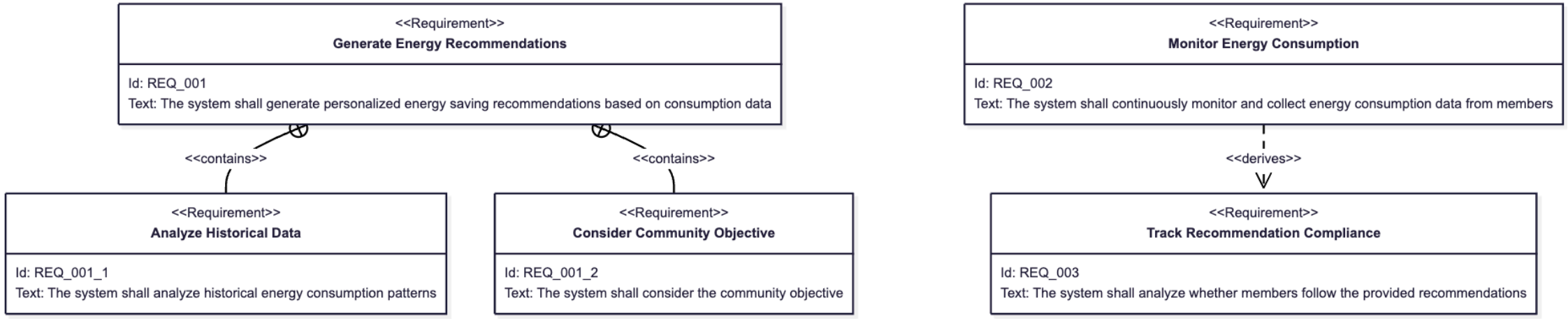
Requirements diagram - the derivation relationship

One can also break more complex requirements into simpler ones using derivation.

Derivation helps to increase tracebality by allowing the user to determine the origin of a requirement and its purpose.



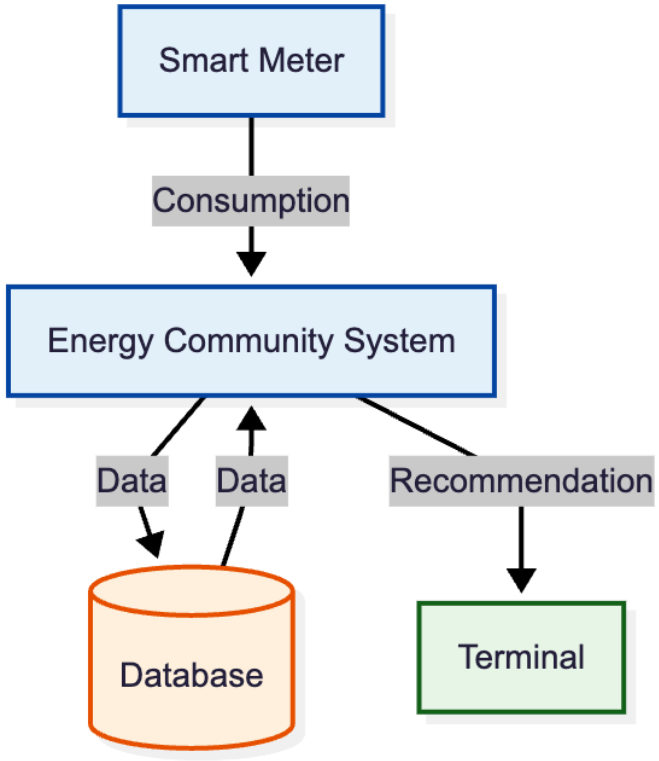
Energy community requirements diagram



Architecture

- Based on the requirements, we must define an architecture for the system.
- The architecture include the technologies that we will use to satisfy the requirements.
- If the requirements diagram describes what the system should do, the architecture describes how the system will be implemented.

Energy community architecture



Summary

- System analysis and design is a key step in the development of a system.
- Use case shows us the interactions between the users and the system.
- Requirements diagram shows us what the system should do, based on the use cases.
- Architecture diagram shows us how the system will be implemented, based on the requirements.

Task

- Design a digital twin for a ski resort (use case, sequence diagram, requirements diagram, architecture diagram)
- The digital twin should monitor the energy consumption of the resort.
- The digital twin should be able to send skiers recommendations to reduce the energy consumption.
- The recommendations are sent via screens installed in the resort.