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Masaccio – Monitoring for urbAn SAfety with the IoT

Deliverable D4 Template

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- *Code can be found in the "implementation" directory.*
- *CAPS files can be found in the "CAPS" directory.*
- *All the diagrams/models are provided in full resolution in the "UML" and "CAPS" directories.*
- *Demo videos that shows the execution of the implemented services can be found at the following links:*
  - Storage (D2) https://youtu.be/RT7HMrQBuiI
  - Actuation (D3) https://youtu.be/YfUbq6JpVns
  - Visualization (D4) https://youtu.be/wh2H0fjx1bE

Challenges/Risk Analysis

Risk	Date the risk is identified	Date the risk is resolved	Explanation on how the risk has been managed
Critical messages delivery times (in case of disaster)	13/11/2017	20/11/2017	We plan on deploying redundant servers (located in a different geographic zone, which host the application) that will go online in case of active server's failures.
Big data storage	13/11/2017	17/11/2017	We plan on using a dedicated NoSQL database to handle that amount of data.
Sensors failures	13/11/2017	24/11/2017	We plan on using redundancy of sensors, which will start working in case of failure (of the active sensors).
Learning of the Kafka framework	13/11/2017	15/12/2017	We plan on using Kafka framework to develop the system: we discovered that it is quite simple to learn and use, even if to exploit its advanced features we had to go deeper into the documentation.
Multi-database integration	20/11/2017	28//11/2017	We plan on using 2 databases at the same time in order to store data: the relational one will store structural information and the NoSQL will store raw data (as the two are not communicating and they contain different kind of data we do not have synchronization problems).
Install devices to existing buildings	04/01/2018	10/01/2018	We could have had problems with the installation of sensors and actuators in existing rooms but: • the door actuators are only installed in standard doors (the anti-panic doors that are installed in common rooms will not be equipped with actuators as these rooms are not access-restricted) • people counters, cameras and smoke sensors are simply mounted on walls and attached to the power grid/network considering those scenarios there should not have problems.

Application Domain

The following architecture is designed to be adaptable to various situations. We are planning to instantiate the problem to the monitoring of the UnivAQ's **existing** buildings.
The following are the main services we want to provide, based on similar systems we analyzed[1] and they are confirmed and update after an interview with Rocco Matricciani (belong to UnivAq's personnel):

- Access control (only certain users are allowed to enter certain areas)
- Security monitoring
  - Air quality control (with respect to, e.g. chemical labs)
  - Smoke detection
  - Firefighting measures
- Alarm dispatching (sirens, loudspeakers) in case of emergencies
  - First responders' communication service
- Smart Information service: provides situational aware information about the monitored area
- Crowd monitoring: analyse the fluxes of peoples inside the UnivAQ's structures to improve lectures/events scheduling and rooms assignments.
  [this one has been reported to be a high interest service by UnivAQ's personnel]
- Data Storing and Analysis: all the gathered data Is stored to be analyzed. The results of such analysis will allow adjustments that will improve the organization of the University. (room assignments, people flows, schedule adjustments, etc.).
- Attendance Registration: allow students to register their attendance to mandatory courses by using their personal card. This allow the personnel to check if a certain student has achieved its amount of presences in a mandatory course.

So, in our instance:

Governance	→	UnivAQ's rector
Areas	→	Buildings, floors, rooms
Citizens	→	Students

List of Assumptions

Assumption	Description
Network availability	We assume that we have network coverage across the monitored areas.
Microcontrollers	We assume that we can use a microcontrollers to manage each sensor.

State of the art

In the field of building monitoring and access control (our instance) the main provided services are [1] [2]:

- Access control: installation of card readers at every critical entrance point, which are connected to a central access control panel. You can assign cards or key fobs that grant access via a user interface or software.

- Web-based Dashboard: browser-based systems are easy-to-use and allow you to access your system at any time from any location with internet connectivity, including your mobile device. This means that you don't have to be tied to your security room to terminate access, lock down doors, or change a schedule.

- Notifications: you'll receive a textual notification for events like unauthorized entry and doors forced or left open.

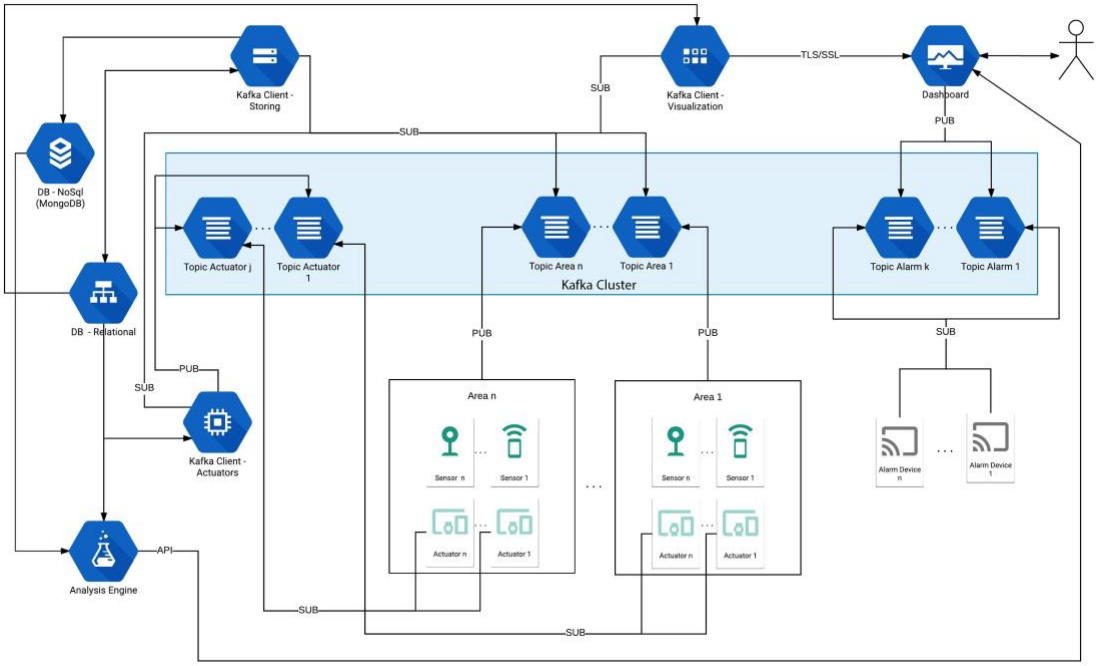
- Video recording: linking your access control system with video surveillance allows you to see exactly who is entering and exiting your building.

- People counters: all buildings are required by law to have an emergency evacuation procedure complete with muster point locations. Access control systems can be designed to provide you with an accurate count of how many people are currently in the building. This allows you to quickly login and check the names and photos of everyone that was in the building before the evacuation.

- Air quality monitoring: air sensors provide novel ways to assess and characterize environments qualitatively and quantitatively in terms of pollution, and human exposure. More specifically, air sensors offer a rare opportunity to assess air quality of indoor environments in real-time. Most IAQ (Indoor Air Quality) sensors, with installed communication protocols, are able to detect and transmit data in real-time to digital platforms, e.g., to a server, PC or smartphone, which in turn broadcast the data to a designated web portal for real-time analysis and visualization.

[1] - http://www.spottersecurity.com/services-access-control-systems/
[2] - http://www.sciencedirect.com/science/article/pii/S0048969716307124

Informal Description of your system and its Software/System Architecture



The system is composed by a **Sensor Network**, an **Actuators Network**, a **Kafka Cluster**, two **DB** (NoSQL and Relational), an **Administration Dashboard** and three **Kafka Clients** (Storing, Visualize and Actuator).

The **Sensor Network** represent the whole sensing subsystem: it senses the environment and communicates the gathered data to the rest of the system publishing on **Kafka Topics**. There will be a Topic for each area (an area may be a building, square, quarter, etc.).

The **Kafka Cluster** is an aggregation of **Kafka Brokers**. A broker receives messages from producers, assigns offsets to them, and commits the messages to storage on disk. It also services consumers (clients), responding to fetch requests for partitions and responding with the messages that have been committed to disk.

The **Kafka Client - Storing** deals with the asynchronous storage of all the raw data collect by the system, by subscribing to the various Area Topics.

The **Kafka Client - Visualize** is responsible to provide refined data to the dashboard and to highlight sensors readings that are out of certain security bounds (those bounds are retrieved from the relational db).

The **Kafka Client - Actuators** reads the data from the sensor network by subscribing to Area Topics and publishes messages on Actuators Topic when certain sensor readings are received, activating the respective actuator(s).

The system stores the raw data on a **NoSQL DB** (MongoDB), this allows for a high flow of data, every reading from a sensor is saved as a *json* file containing the identifier of the sensor, the identifier of the area the sensor belong and the actual reading.

The **Relational DB** is used to store the structure and organization/disposition of the various devices (sensors and actuators) across the areas. It also stores the data regarding the user's authorizations to access certain areas and the various services provided by the system.

The **Administration Dashboard** receives data from the **Kafka Client - Visualize** through a secure connection, then it displays the received data to the user. It also shows a warning when there are sensor's readings that are not within certain "safe" bounds. In those cases, the systems ask the user for a check before emitting an alarm message that, in case of confirmation is published on Alarm Topics that will trigger the respective Alarm Devices.

The **Actuator Network** represent the whole actuation subsystem: the actuator waits for actuation messages to be published on its Actuation Topic, when such message is published the actuator activates and publishes on the Area Topic that it has performed a certain action.

The **Analysis Engine** is responsible to perform batch/background data analysis on the previously stored data, and to make available an interface to allow the dashboard to display such data.

Architectural Pattern

The main architectural pattern used in the system is the Publish/Subscribe pattern. Publish/subscribe messaging is a pattern that is characterized by the sender (publisher) of a piece of data (message) not specifically directing it to a receiver. Instead, the publisher classifies the message somehow, and that receiver (subscriber) subscribes to receive certain classes of messages. Pub/Sub systems often have a broker, a central point where messages are published, to facilitate this.

Publish–subscribe is a sibling of the message queue paradigm, and is typically one part of a larger message-oriented middleware system. This pattern provides greater network scalability and a more dynamic network topology.

To implement this pattern we chose to use **Apache Kafka**. Apache Kafka is often described as a "distributed commit log" or more recently as a "distributing streaming platform." A filesystem or database commit log is designed to provide a durable record of all transactions so that they can be replayed to consistently build the state of a system. Similarly, data within Kafka is stored durably, in order, and can be read deterministically. In addition, the data can be distributed within the system to provide additional protections against failures, as well as significant opportunities for scaling performance.

User Stories

Functional requirements

FR1: the system has to monitor several areas.

- FR1.1: the system exploits a sensor network in order to read data.
- FR1.2: the system has to collect raw data from sensors.
- FR1.3: the system has to store the sensed data.
- FR1.4: the system has to organize the collected data and has to provide a way of checking users accesses on restricted areas.
- FR1.5: the system has to analyse and produce statistics about the collected data.

FR2: the system has to provide a set of visualization tools in order to show the current state of the monitored areas and highlight crucial situations.

FR3: the system has to provide a set of actuators that support the human user actions in case of emergencies.

Extra-Functional requirements

EF1: dependability

- EF1.1: availability - the system has to correctly and continuously operate under the regular hardware state/condition.
- EF1.2: safety - the system has to avoid false alarms and other unwanted behaviors that may be dangerous for user's safety.
- EF1.3: security - the system must ensure that the data and the services are accessed only by the authorized users.
- EF1.4: fault-tolerance - the system has to be operative even in case of disasters (with an eventual degraded mode) and has to guarantee that no critical messages are lost and delivered in at most 5 seconds.

EF2: performance - the system has to handle 40.000 messages per hour coming from (up to) 2.000 sensors, the sensed data are collected within different time ranges (from a few seconds to few minutes, with an average of one message every 180 seconds).

EF3: scalability - the system should be easily upgradable (in terms of new areas and sensors added to the network).

EF4: usability - the system has to be easy to use for the end user.

User stories

- Citizen

    1. *<citizen>, <FR2, FR3, EF1.2, EF1.1, EF4>*
       As a citizen, I want to feel safe: in case there's an emergency I would like to receive a notification of how to behave and possibly which areas of the city it is best to avoid.
    2. *<citizen>, <FR3, EF1.3, EF1.1, EF4>*
       As an authorized user, I want to be able to access the areas for which I have permission.
    3. *<citizen>, <FR2, EF1.2, EF4>*
       As a citizen, I want to be informed about the crowding of the structures: I would like to avoid crowded areas because I'd prefer to avoid crowded rooms.

- Emergency Operator

    1. *<emergency operator>, <FR2, FR3, EF1.1, EF1.4, EF2, EF4>*
       As a safety operator, when there's an emergency, I need to be alerted by a notification that indicates me where the emergency is, so I can go to help people as soon as possible.
    2. *<emergency operator>, <FR2, EF1.1, EF1.4, EF4>*
       As a safety operator, I want to be informed about the current situation of the place where I am, to monitor it and avoid critical situation.

- Security Manager

    1. *<security manager>, <FR3, EF1.1, EF1.3, EF1.4>*
       As a security manager, I must ensure that only the authorized people access the restricted areas.
    2. *<security manager>, <EF1.3>*
       As a security manager, I have to make sure that the collected data is not accessed by unauthorized people.
    3. *<security manager>, <EF1.3>*
       As a security manager, I have to guarantee the privacy for the people and keep their sensible data safe.

- Sensor Network Administrator

    1. *<sensor network administrator>, <FR1.1, FR1.2, EF1.1, EF1.2, EF1.4, EF2>*
       As sensor network administrator, I have to ensure that all the sensors operate correctly.
    2. *<sensor network administrator>, <EF3>*
       As sensor network administrator, I want to be sure that if the number of sensors increases, the system still works as intended.

- Database Administrator

    1. *<database administrator>, <FR1.3, FR1.4, EF1.1, EF1.4, EF2>*
       As a database administrator, I have to ensure that the databases are correctly working at any time.
    2. *<database administrator>, <FR1.3, FR1.4, EF1.3>*
       As a database administrator, I have to be sure that the data is not accessed by unauthorized people.

- Governance

    1. *<governance>, <FR1.5, EF1.1, EF1.2, EF1.3>*
       As the government, I'm concerned about citizens safety, security and information retrieved by data analysis.

- System Administrator

    1. *<system administrator>, <FR1, FR2, FR3, EF1, EF2, EF3, EF4>*
       As a system administrator, I'm concerned about every aspect of the system.

Views and Viewpoints

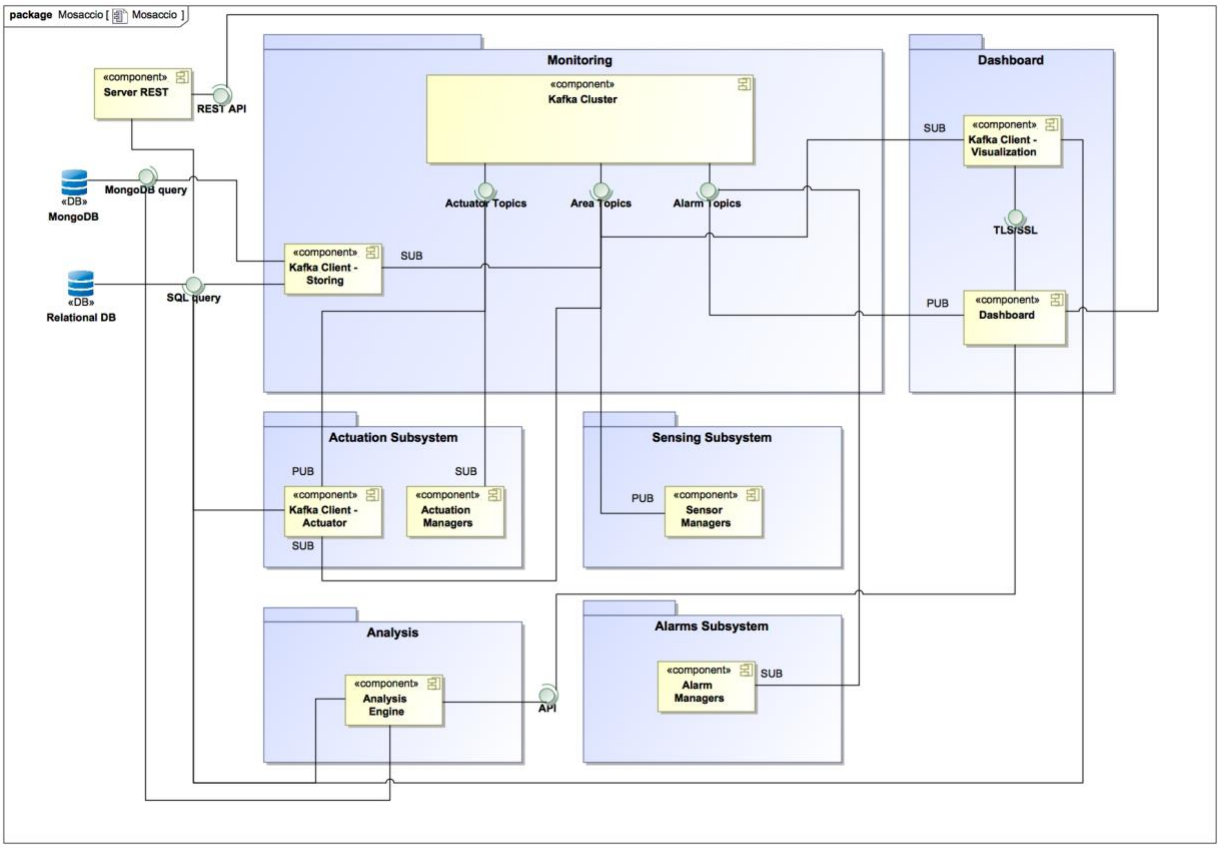
Stakeholders:

- Citizen
- Emergency Operator: is the user's class that is responsive into the safety of the citizen.
- Security Manager: is the user responsible of the cyber-security of the system.
- Sensor Network Administrator: is the user responsible of the proper functioning of the sensors and the network where the MASACCIO system is deployed.
- Database Administrator
- Governance: is the customer who requested and paid for the deployment of the system.
- System Administrator: is the user responsible of the whole system.

	Citizen	Emergency Operator	Security Manager	Sensor Network Administrator	Database Administrator	Governance	System Administrator
Security	X		X		X	X	X
Privacy	X		X		X	X	X
Sensing				X			X
Emergency Response		X					X
Energy Consumption				X			X
Networking & Communication				X			X
Usability	X	X					X
Dependability	X	X		X			X
Performance	X	X		X			X
Costs				X		X	X
Citizen Engagement						X	X
Data Analysis					X	X	X

UML Static and Dynamic Architecture View

Static Architecture View



Monitoring: is the subsystem dedicated to the collection of the data. It is composed by:

- **Kafka Client - Storing:** is the component dedicated to the storing of the sensor's data on the NoSQL database. When it is started it collects the list of the Area Topics from the relational database. Then it subscribes to all those topics and every time a message is published on such topics it performs an insertion query on the NoSQL database, storing the message (sensor's lecture/actuator's log) and other information such as the time it was submitted, and the identifier of the device.
- **Kafka Cluster:** is the main component of the whole system, it is composed by several *Kafka Brokers* that are the sub-components that are responsible of the exposition of the 3 main classes of interfaces: *Actuator Topics*, *Area Topics* and *Alarm Topics*. Each of them represents a group of "physical" topics. *Area Topics* includes all the single Topics regarding the monitored Areas (there is a Topic for each Area, in general every Area is monitored by several sensors and contains several Actuators). *Actuator Topics* includes all the Topics that are used to trigger the Actuators (this mechanism will be better described in the sequence diagrams). *Alarm Topics* is similar to *Actuator Topics*, contains the Topics used to trigger the alarm devices (this mechanism will be better described in the sequence diagrams).

Sensing Subsystem: every sensor is managed by a microcontroller capable of running Java code. Those microcontrollers are referred as *Sensor Managers*. Those components are responsible to fetch the sensors readings and publish messages containing such data to the respective *Area Topic.*

Actuation Subsystem: the Actuation Subsystem is composed by 2 parts:

- Kafka Client – Actuator: this component is a kafka client who listens (is subscribed) to all the *Area Topics*, when it reads a message who contains a sensor reading which is supposed to trigger an actuator (this information is stored on the relational database) it published a message on the respective *Actuator Topic*.
- Actuator Managers: it follows the same structure as *Sensor Managers.* They are responsible of listening, by subscribing to the respective *Actuation Topic,* for actuation messages. Those messages are generated by the *Kafka Client – Actuator*, when an actuation message is published on *Actuator Topic X*, it is read by the *Actuator Manager Y* who triggers the *Actuator* (physical device) *Z*.

Alarm Subsystem: every alarm device is handled by a microcontroller (just like in the *Sensing Subsystem*). Those microcontrollers form the *Alarm Managers* component, each element of this component listens (is subscribed) to the respective *Alarm Topic*, when a triggering message is received on the Topic of interest, the respective alarm device is triggered by its microcontroller.

Analysis: is the subsystem that contain the *Analysis Engine* component. This component contains the logics that is responsible to compute analytics on the gathered data. It can be accessed by a dedicated API by the other component of the system.

Dashboard: contains the component that are dedicated with the visual representation of the data. It is composed by the following components:

- Kafka Client - Visualization: this component is a Kafka client who is subscribed to all the *Area Topics.* It analyzes all the incoming sensor's lectures and checks if the sensed data is inside certain defined "safe" bounds (that are retrieved from the relational db). If a reading is out-of-bounds, then a notification is displayed on the dashboard itself.
- Dashboard: is the component that allows the operators to visually see the incoming data (in real-time, received by the *Kafka Client – Visualization*) and to receive alarm notifications. When an alarm notification is received, the situation is checked by an operator who confirm/reject the dispatch of the alarm associated to that situation. If the alarm is confirmed the triggering message is published on the respective *Alarm Topic*. The *dashboard* also accesses the analysis engine to allow the users to visualize the result of more complex analyses.

Relational DB: is the database who contains the data that refers to the structure of the system/system's organization. For instance: sensor's positions, user's authorizations, etc.

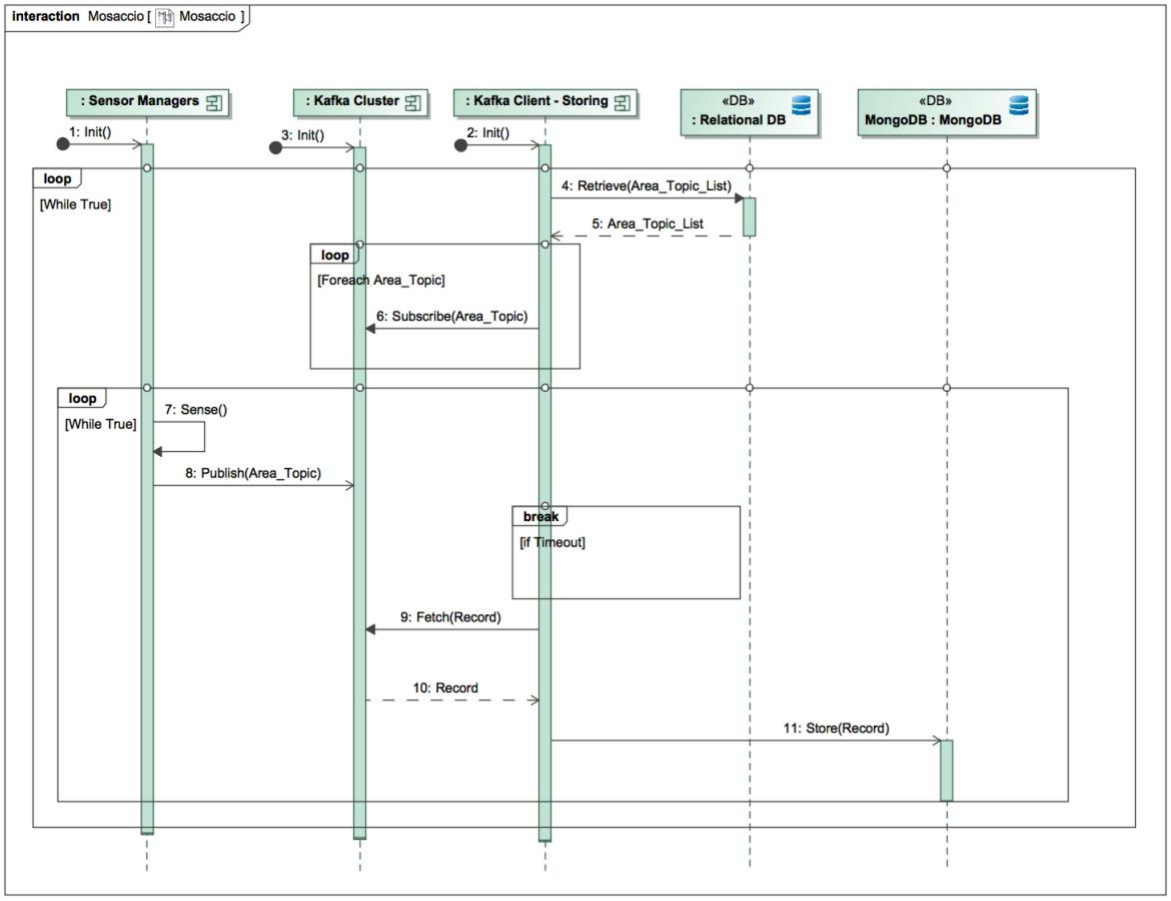
MongoDB: is the database that contains only and all the sensed data coming from the sensors.

REST Server: is the component that represent the REST Server with which the dashboard interacts to retrieve the data from the databases and access the services.

Dynamic Architecture View

Dynamic view of the system for the **D2** implemented service: **Storing**

The following sequence diagram describes the ***storing process.*** That is the procedure who is responsible to the collection of the sensed data and the storing on the databases.
We decided to ***implement*** this feature because it is the core functionality on which all the other ones are based on. This allows us to test the performance/usability/behavior of the system.



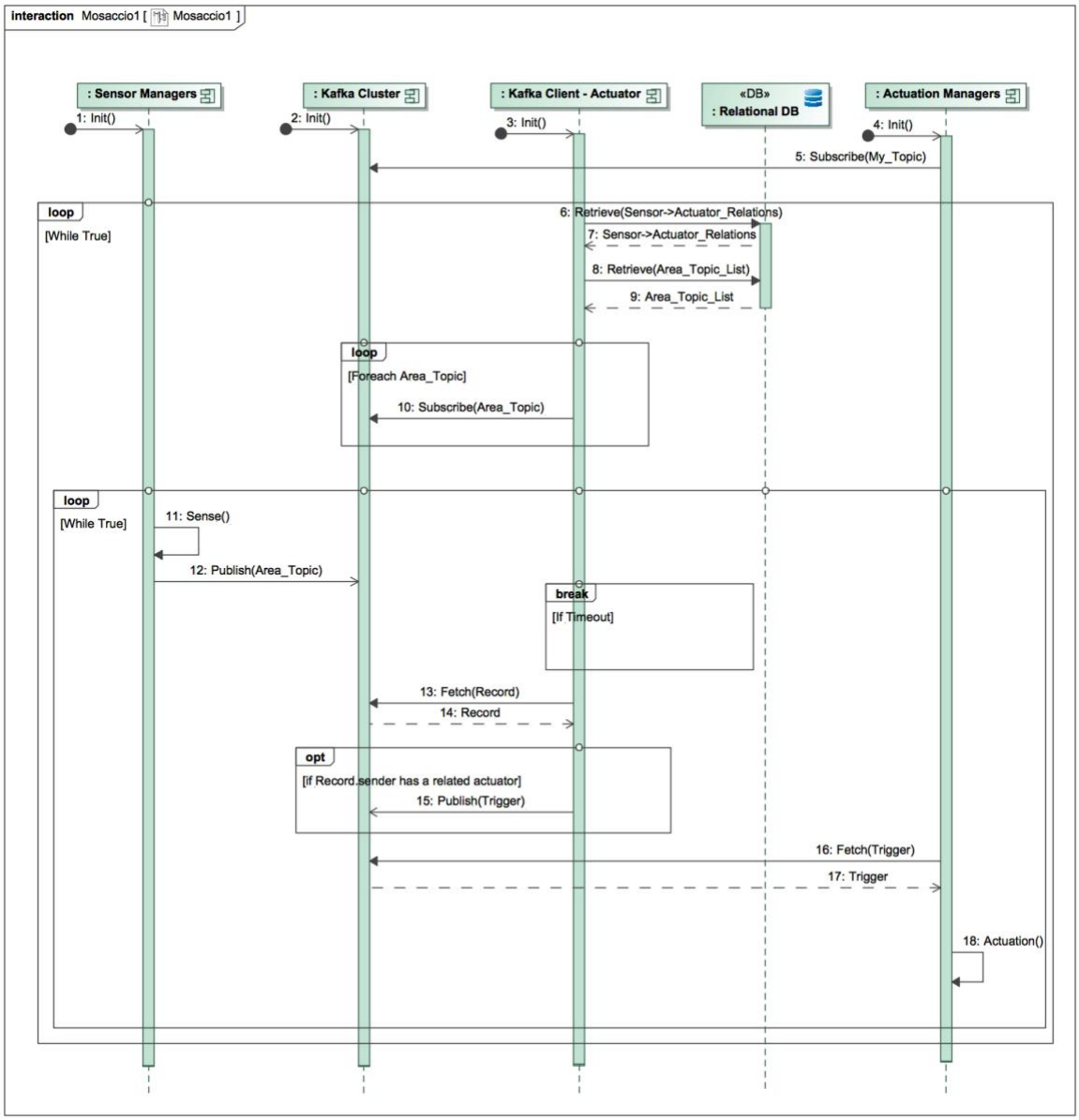
At the beginning, the **Sensor Manager**, the **Kafka Cluster** and the **Kafka Client – Storing** are initialized (are running).
During the initialization phase the *Kafka Client – Storing* fetches the list of all the *Area Topics* from the *Relational database.* Then, it subscribes to all the retrieved *Area Topics*, now it is ready to listen for messages.
At this point the sensor is up and running and it starts to sense the environment, and (through its manager) it publishes the message containing the sensed data to its *Area Topic*.
If the timeout is reached a break in the inner loop interrupts the execution, otherwise the message is received from the Kafka Client – Storing which then asynchronously deserializes it to a *.json* file and stores it in the *MongoDB database*.

Then the cycle repeats, but after a configurable amount of time, the Kafka Client – Storing pauses and updates the list of all the *Area Topics* from the *Relational database*, then continue his normal execution.
Obviously, in this representation, we are looking at the execution from the point of view of a single sensor who is sending its lectures, but in the real execution there will be several sensors and several sensors managers which will publish their message to the *Area Topics.*
By "*publishing to the Area Topic*" we are implicitly saying that the device transmits its message to the cluster through its Sensor Manager.

Dynamic view of the system for the D3 implemented service: Actuation

The actuation service consists of the triggering of some actuators when a certain sensor senses a certain event (e.g. a user slides his card on a card reader -> the door opens).
The implementation of this service allows us to further test our architecture, adding components and seeing how they can work together.

The execution is considered from the point of view of 1 sensor that triggers 1 actuator (we have more sensors/actuators in the demo video).



The Actuation Manager subscribes to its Actuator Topic and waits for a triggering message.
The Kafka Client - Actuator retrieves from the relational database the list of the pairs *sensor -> actuator* (from the table sensors_actuators). This allows the client to know on which Area Topics it needs to be subscribed.

In fact, through a dedicated query the Kafka Client - Actuator only subscribes to the Area Topics in which there is at least 1 sensors that triggers an actuator.
Once the Kafka Client - Actuator retrieves the list of Area Topics from the relational database it subscribes to them.
In the meantime, the Sensor Manager is running and starts sensing the data from its sensor, once the data is sensed It asynchronously publishes it on its topic.

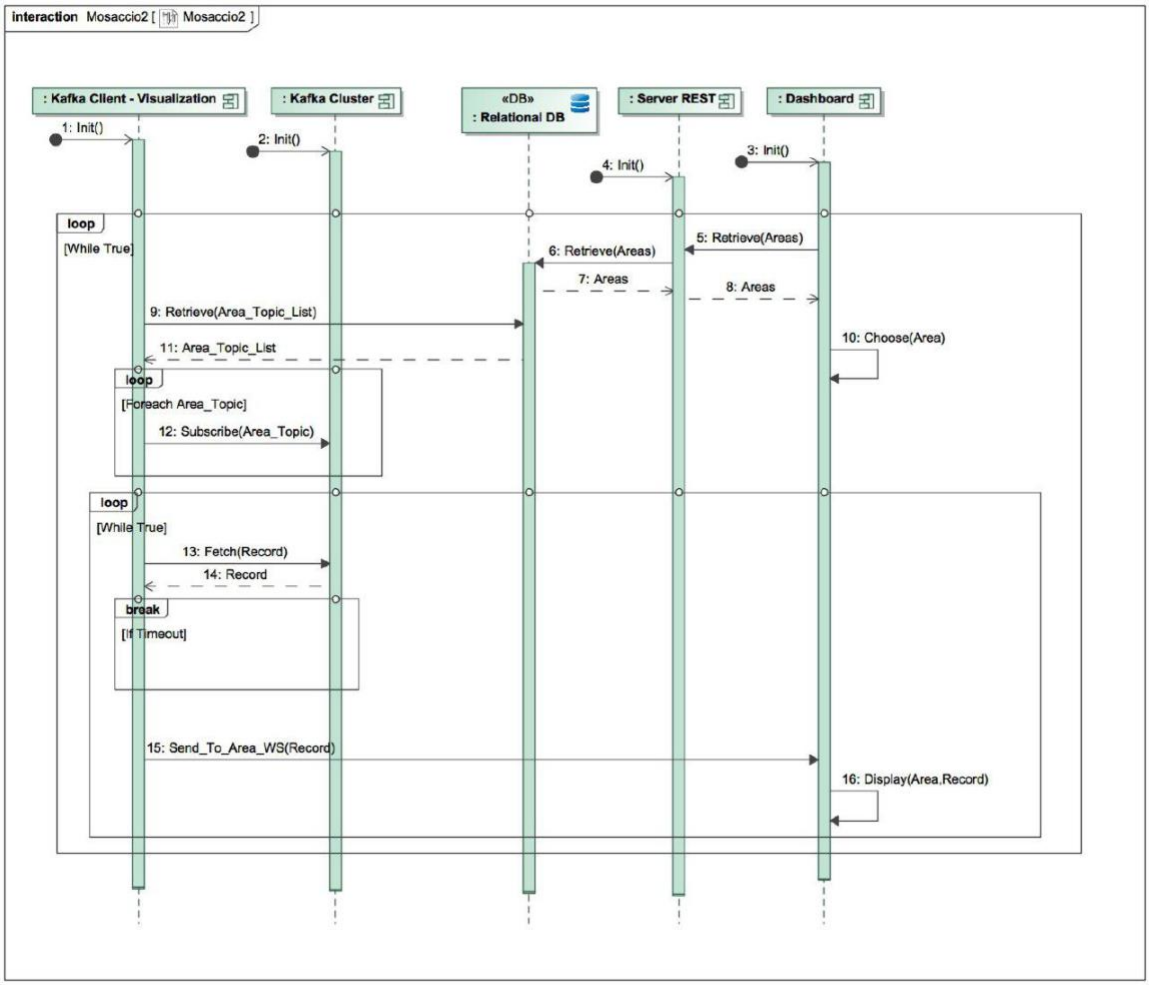
Then the Kafka Client - Actuator receives the message, check whether or not the sensor that sent it is related to an actuator and in this case, it asynchronously publishes it to the respective Actuation Topic, it otherwise ignores the message.

The Actuation Manager that was listening to its topic then receives the message sent by the Kafka Client - Actuator and triggers the actual actuator (the physical device).

Just like the Kafka Client - Storing, the Kafka Client - Actuator restarts every X seconds, refreshing the data coming from the databases, so it is easy and immediate to add more sensors/actuators to the system without manual intervention.

Dynamic view of the system for the **D4** implemented service: **Visualization**

This service allows the personnel to visualize the data sensed by the sensors in a particular area. In general, it allows to manage the system.
The implementation of this service allows us to demonstrate how the data can be visualized and handled in real-time, even if other crucial components such as the Storing Client and the Actuation Client are not running.



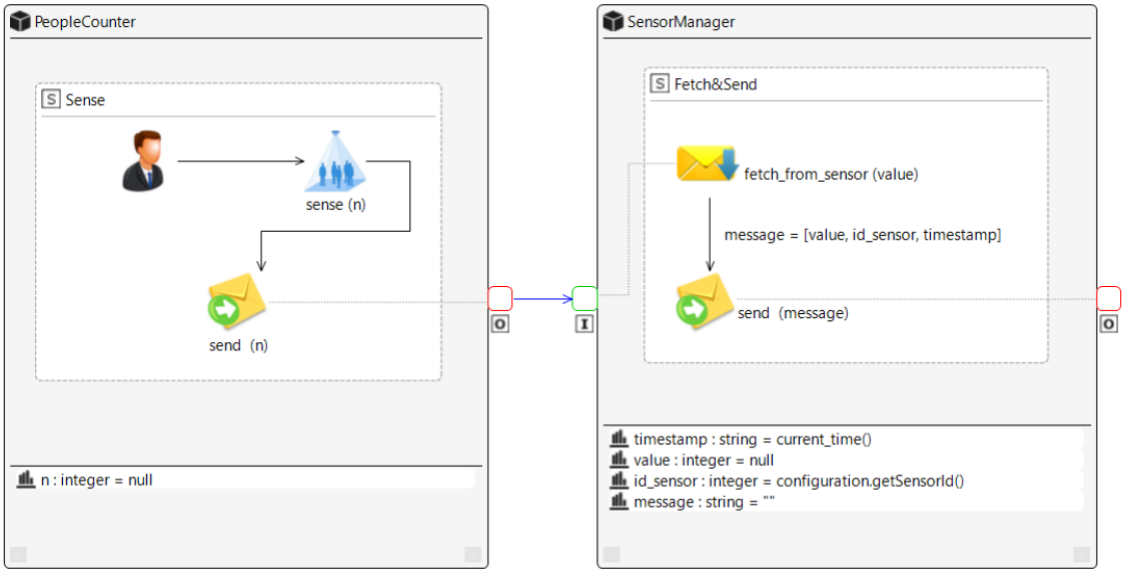
When the **Dashboard** is accessed, it retrieves the list of all areas stored in the **relational DB** through a REST request to the **REST Server**. So, the user can see all the monitored areas and he can choose which particular place he wants to inspect.
In the meantime, **Kafka Client – Visualization** retrieves the list of all areas from the **relational DB** and subsequently, it subscribes to each **Area Topic**.
Once registered to each topic, the **Kafka Client - Visualization** starts to retrieve the records that contains the sensed data from the Kafka Cluster and send them to the dashboard, using a **websocket**. When the user chooses the area he wants to monitor, the **Dashboard** subscribes to the **websocket** related to that area, then the Dashboard starts to receive the data from the **Kafka Client – Visualization**, it shows them by displaying in a time graph and in a list (other solutions can be easily implemented).

CAPS Architecture View

CAPS SAML

In this section, we present some of the devices that are used in our architecture.
All the representations are quite minimal because all the logic and the checks are provided by server(s) and so the received/sent messages do not need refactoring (or do need in a minimal part); that is an intended behavior as we want that the critical operations are executed on the most reliable part of the system.

People Counter

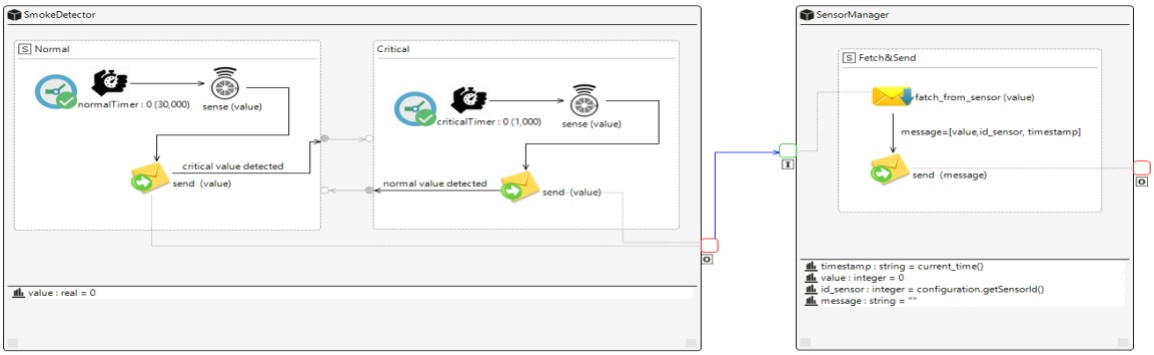


The **PeopleCounter** component represent the actual device.
When a person enters/leaves the room/area the device computes the current room/area occupation and send this information to its **SensorManager**.

The **SensorManager** build the final message by adding the sensor id and the timestamp in which the lecture has been made and publishes the message to the respective Kafka topic (as shown in the sequence diagrams for both the developed services).
NOTE: the out-message port at the right side of the **SensorManager** component is connected to the Kafka cluster (described in the component diagrams/sequence diagrams), that's why it has not represented in the CAPS notation.

The **SensorManager** component is repeated for all the other devices so its description will not be reproposed.

Smoke Detector

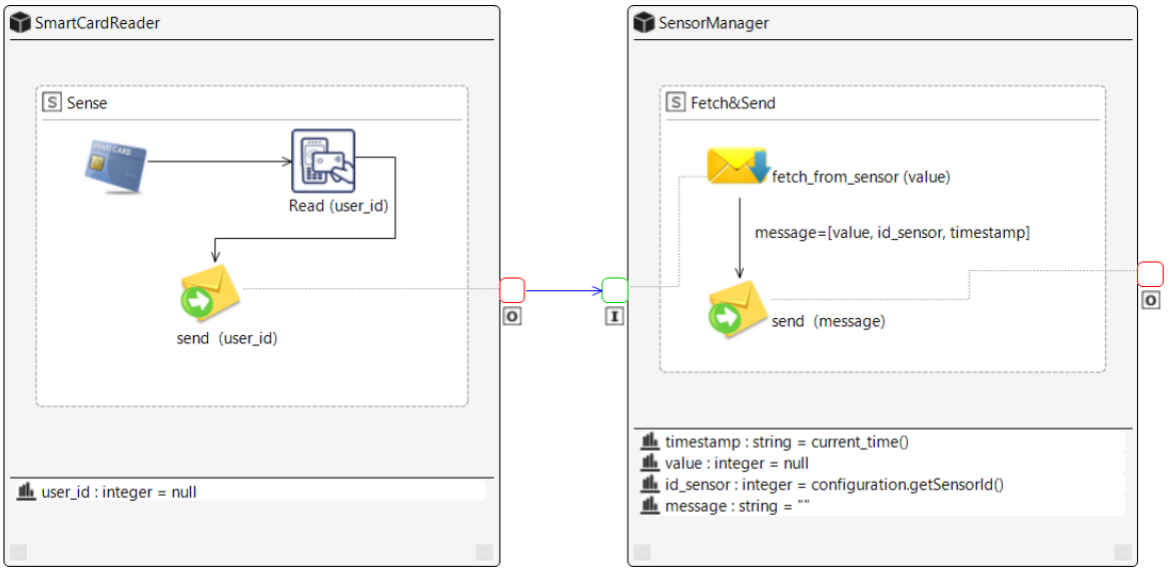


The **SmokeDetector** component is composed by two operative modes:

- **Normal:** it’s the mode in which the sensor operates in case of the sensed values are defined as “normal” and so they not imply a dangerous situation. In this mode, the readings are made every 30 seconds.
- **Critical:** It’s the operative mode in which the sensor enters in case of abnormal readings, in this mode the readings are made every second. If the sensor sees a “normal” value it enters again in **Normal Mode**.

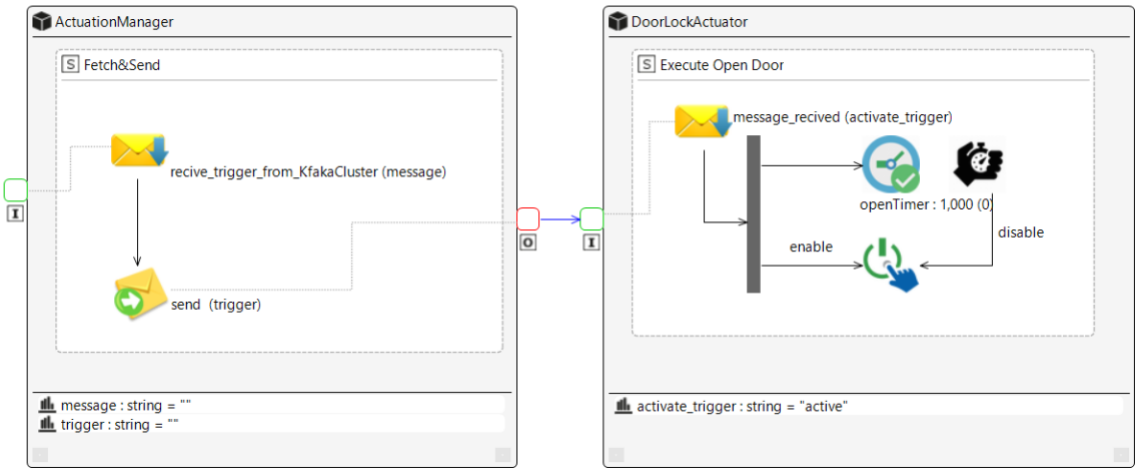
The component is equipped with a periodic timer with no delay, in **Normal Mode** the timer expires every 30 seconds, in **Critical Mode** in 1 second.

Smart Card Reader



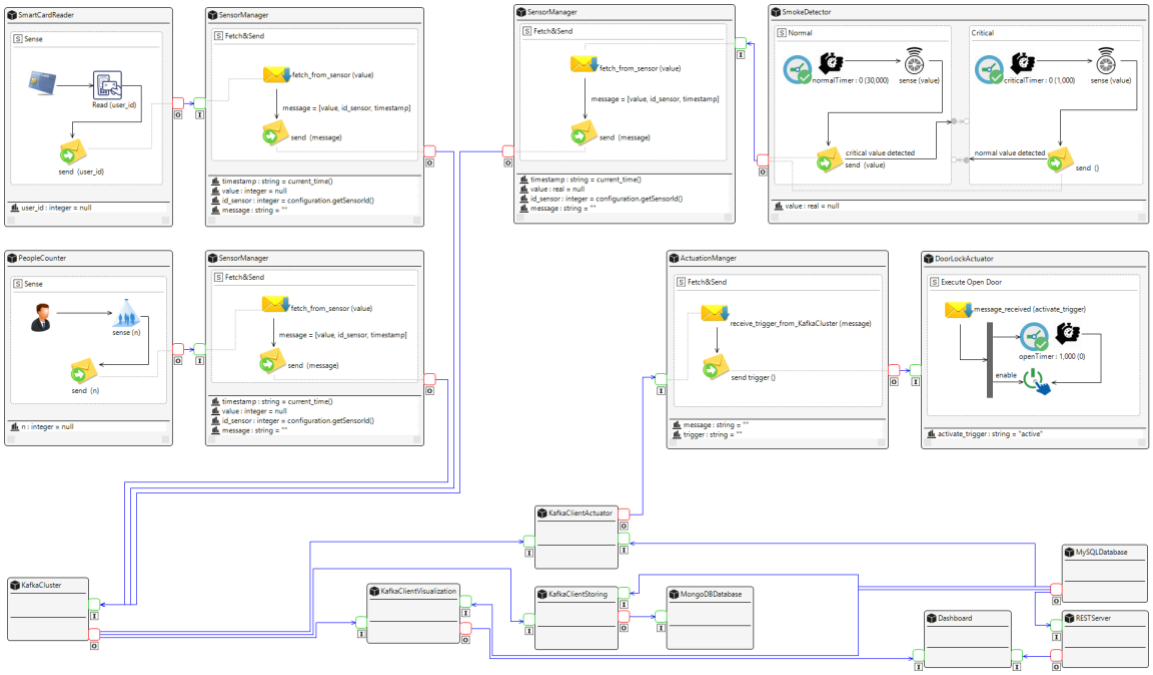
The **SmartCardReader** component represent the physical device that is installed at the side of the door/area entrance, to filter the accesses.
It reads the used id from the card when the user passes it on the reader, and sends that information to the **SensorManager**.
We only use the user id (without its access level or other information) because we want the system to interactively check for the user's permissions.

Door Lock Actuator



The **DoorLockActuator** receives a triggering message from its **ActuationManager** (the **ActuationManager** receives it by subscribing to the respective **Actuator Topic**).
When a trigger is received a timer is fired, the timer is not periodic but has a delay of 1 seconds before it expires. The same message opens the door lock, when the timer expires the lock is closed again.

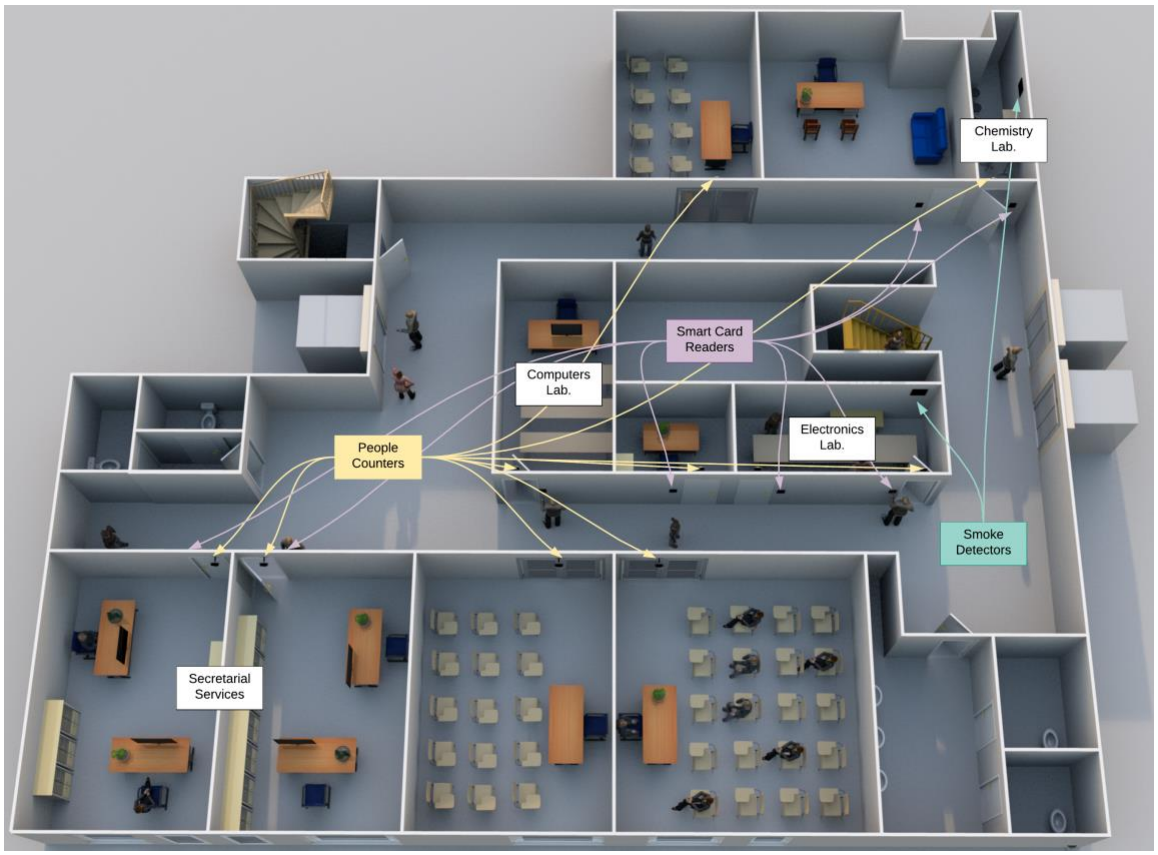
UPDATE: As suggested by Mohammed we also provide a full system CAPS SAML view (the Kafka Client, the databases and the Dashboard are seen as black boxes, because they have already been described in the previous sections; moreover, CAPS is not suited to describe those kind of components):

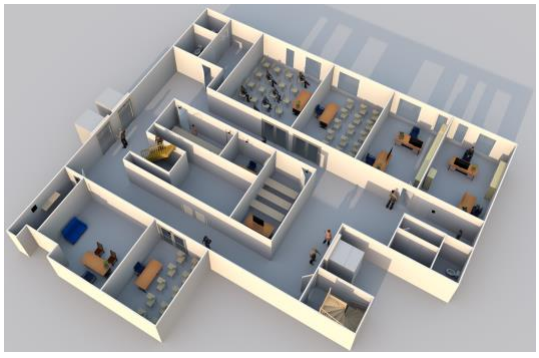


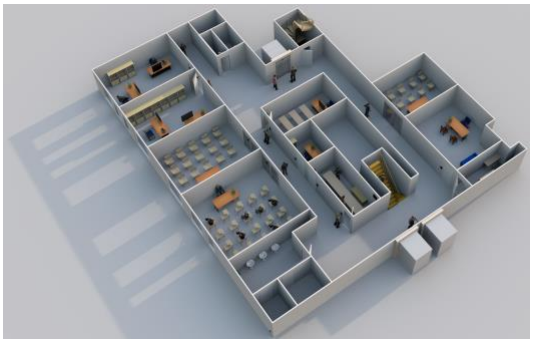
CAPS ENVML

The follow ENVML representations describe how the system is integrated in the UnivAQ's buildings, in particular we have chosen to represent the first floor of Coppito 2 because we consider it as an interesting area of the building; it contains several lecture rooms, 3 laboratories and the secretarial rooms.

NOTES: full resolution images are available in the *"CAPS/ENVML"* directory.
Please also note that the devices (people counter, smart card readers, smoke detectors) have been represented using models that are not meant to be used for that purpose, so it may be possible that certain items are positioned in a "strange" way or are represented with wrong scale/dimensions.







As showed in the above pictures we have People Counters positioned in almost all rooms (on top of the door, as suggested by the device's manufacturer), in particular in all the lecture rooms, the secretary rooms, and the laboratories.

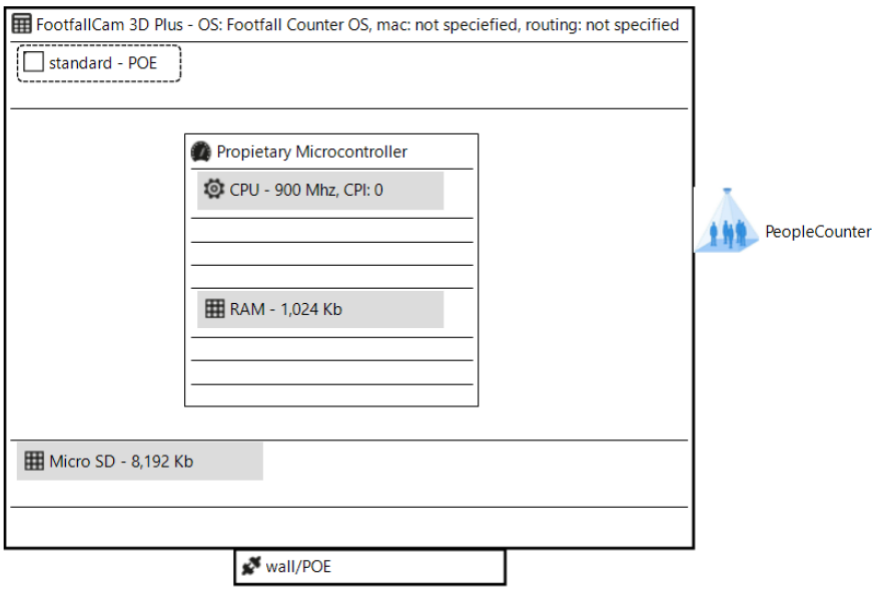
Smart Card Readers have been positioned in restricted access rooms such as the laboratories and private offices, they are positioned at the side of the door.

Smoke Detectors have been placed in rooms that have a high degree of dangerous substances inside them such as the electronics lab. and the chemistry lab.
They have been placed on the walls, above the working benches even if the position is not really important because (at least for the devices that we have considered) they are able to cover pretty large areas.

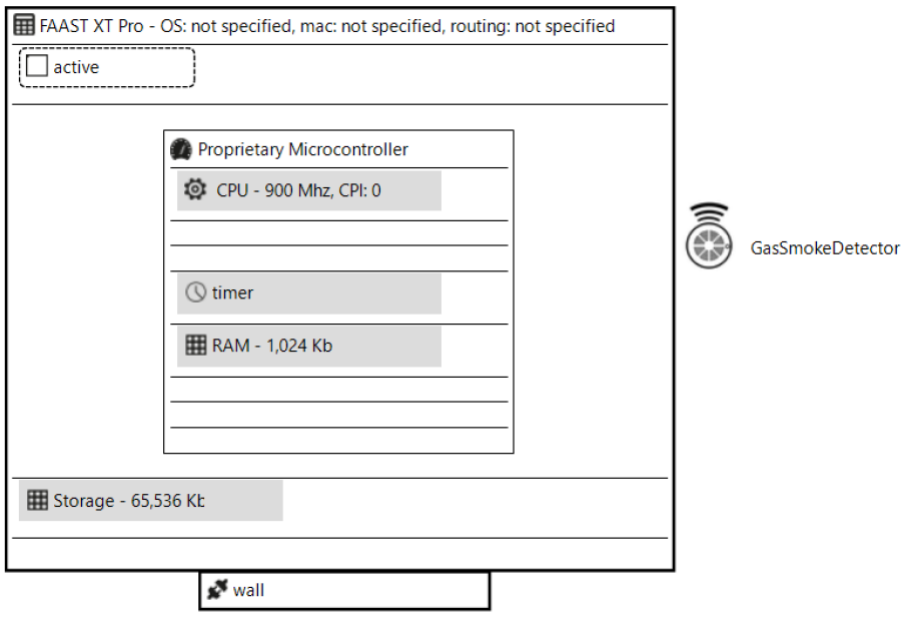
CAPS HWML

In this section, we provide the hardware specification of the sensors exposed in the SAML representations.
The provided HWML models are purely indicative of the hardware that can be used to implement the system's services. As previously stated the sensors can and should be extremely simple as they do not perform (or do perform very little) computation.
However, we wanted to provide real examples of devices with their real specifications anyway.

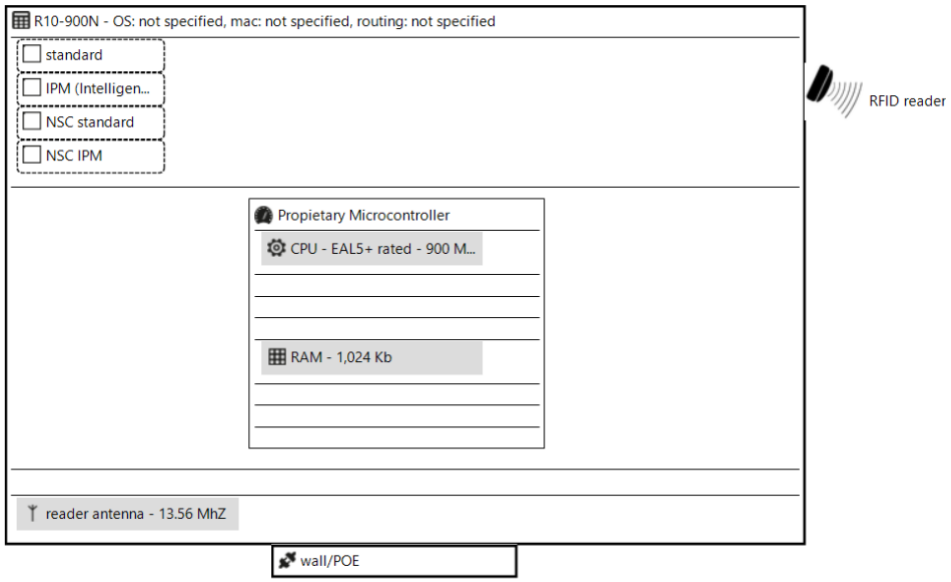
People Counter [1]



Smoke Detector [2]



Smart Card Reader [3]



[1] - http://www.footfallcam.com/Product/3DPeopleCounter
[2] - https://www.systemsensor.com/en-us/Pages/FAAST%20XT%20Pro%209440X.aspx
[3] - https://www.rfideas.com/products/door-readers/hid-r10-model-900

CAPS Design Decisions

The developing of the CAPS models confirmed the architecture we had built in the previous deliverables. In particular, as we have concentrated all the logic on the "server side" (or better, in the Kafka Clients) the physical devices we can use are extremely simple because all that they have to do is to sense and forward the lecture to their Sensor Manager.
So, we have not made other decisions regarding the system's architecture.

The only thing we would prefer is to deploy the devices in a wired environment, both with respect to the power supply and the network connection, even if this is not strongly required as the system is designed to tolerate network disconnections without data losses (for reference, the demo videos have been recorded in a wireless environment).

Design Decisions

The rationale by which we decided the following strategies/tools are described at the end of the document using Architectural Knowledge design SPAce Modeling (AK-SPAM) tables.

- Storing

  The storage is achieved by utilizing two kinds of databases. The NoSQL database (we are planning to use MongoDB) will be used to store raw data, or more in general all the data coming from the various sensors and actuators. The reading of the sensor is stored as a *.json* file containing the id of the sensor, the id of the area the sensor is operating in and the sensor's reading. We chose a NoSQL db because we want to be able to store huge amount of data with the smallest amount of latency we can achieve. MongoDB as a documental db allow us to organize the data in a way that is particularly suited for our use. Allowing the definition of time to live for the stored data, decentralization, great scalability and replication (data redundancy and automatic failover).
  In particular in our system we have a volume (in average) of 40.000 messages per hour, that means 960.000 per day and 432.000.000 per 15 months, that is the suggested time interval in which data should be kept to maximize the analytic value [3].
  Moreover, it is easier for us to store sensed data in an unrelated way using a NoSQL db then storing them in a relational one.
  The NoSQL db is coupled with a relational db that is used to store the data regarding the authorizations, sensor-area organization, and other general information about the system that needs to have a strict structure.
  A dedicated Kafka Client is appointed to the storing of the incoming data. It is subscribed to all the area topics and it is only responsible of inserting all the incoming readings into the NoSQL db, it uses the relational one to verify sensors dispositions etc.
  As the client is dedicated we are removing load and overhead from the other component of the system allowing for even more performance.
  As requested, a REST interface is used to wrap the system for external (by external we mean "outside" of the system) querying.

- Sensors organization

  We chose to organize the sensors in areas, each area describes a geographical zone around the city and contains different sensors and actuators. This allow the system to have **great scalability** as if we need to add more sensors/actuators we just need to install them and let them publish their messages to the dedicated area topic.

- Data acquisition

  We discarded the possibility to use a **pure event driven** approach because, after analysing the pattern we identified several criticalities such as: resilience is more difficult to achieve in an pure event-driven system due to the short-lived nature of event consumption chains, when processing the event, the listeners have to immediately react to and transform the result, these listeners typically handle success or failure directly and in the sense of reporting back to the original client [6]; the flexibility of event driven architecture raises complexity when the application grows. The reason is that one event triggers a range of routines, and with more events it becomes unpredictable. The type and amount of routines is not specified causing some components to behave in an unpredictable manner.
  An event driven architecture is easy to develop but hard to control [8].

  In **Pub/Sub** we have strong advantages that strictly concerns our system, such as [7]:
  - dynamic targeting: instead of maintaining a roster of peers that an application can send messages to, a publisher will simply post messages to a topic.
  - decoupling and scalability: publishers and subscribers are decoupled and work independently from each other, which allows you to develop and scale them independently. You can decide to handle orders one way this month, then a different way next month.
  - simplified communication: the Publish Subscribe model reduces complexity by removing all the point-to-point connections with a single connection to a message topic.

  One of the strong disadvantages of the Pub/Sub architectural pattern is that there could be difficulties when it is decided to modify the message structure, but this does not apply to our instance as every sensor microcontroller will always publish the same message in the same format.
  Plus, event driven techniques can be adopted on top of the Pub/Sub skeleton if ever needed.

  We chose to follow the PubSub architectural pattern and to implement it using **Apache Kafka**, because as a framework, adds important features to the classic Pub/Sub pattern.
  Kafka allows to implement secure real-time streaming data pipelines that reliably get data between systems or applications and secure real-time streaming applications that transform or react to the streams of data [4].
  Kafka can be used to stream data, as a message dispatcher and as a storage system.
  Security is achieved by encrypting the data transferred between brokers and clients, between brokers, or between brokers and tools using SSL/TLS.
  Kafka also allow for a throughput of millions of records/second [5], replication, redundancy, scalability, decentralization and fault tolerance that are the crucial points of our system.
  Moreover, Kafka is extremely immediate to use even if it requires a certain degree of expertise to exploit all of its features.

The sensors are organized in areas, each area has its dedicated topic, so the sensor belonging to the area *x,* publish its reading to the topic of the area *x*, the published message consists of the id of the sensor itself and the actual reading.

- Visualization and analysis

  A dedicated Kafka Client is responsible to read the incoming data from the area topics (just as the client dedicated to the storing) and transmit them with a secure connection to a dashboard.
  The data can be subjected to analysis and refactoring before being sent to the dashboard.
  The data is displayed in form of graphics, having a dedicated client that directly (i.e. without necessarily going through the database(s)) allow us to eliminate the overhead that would have been present otherwise.
  Sensors readings that are out of certain "safe" bounds (retrieved from the relational db) will trigger a warning notification to be displayed in the dashboard.
  An operator that sees the warning can activate an alarm. Triggering an alarm is achieved by publishing on the topic dedicated to that alarm (or alarms) device(s), these devices will be activated by the published messages.
  Data could be analysed even in an "offline" way by accessing the data through the REST APIs.

- Actuation

  Another dedicated Kafka Client is subscribed to the area topics. When it reads a message that implies the triggering of an actuator, it publishes to the topic related to that actuator (also more actuators could be subscribed to that topic) activating it (or them).
  As for the sensors organization, this pattern allows for a high factor of scalability, as for introducing more actuators is enough to install them, allow them to publish on their topic and insert the record *sensors reading -> actuation* into the relational db.

[3] - https://www.datadoghq.com/blog/monitoring-101-collecting-data/
[4] - https://kafka.apache.org/intro
[5] - https://engineering.linkedin.com/kafka/benchmarking-apache-kafka-2-million-writes-second-three-cheap-machines
[6] - https://www.reactivemanifesto.org/glossary#Message-Driven
[7] - https://aws.amazon.com/pub-sub-messaging/benefits/
[8] - https://www.linkedin.com/pulse/event-driven-architecture-michel-herszak/
[9] - https://benchmarksgame.alioth.debian.org/u64q/python.html

Concern (Identifier: Description)		*Con#1: How can we gather the data from the sensors?*
Ranking criteria (Identifier: Name)		*Cr#1: Reliability - all messages must be received* *Cr#2: Fault-tolerance - the system must be resilient to failures and critical conditions* *Cr#3: Performance - the messages must be received in real-time* *Cr#4: Scalability - the system must be easily scalable (by means of adding sensors/areas)*
Options	***Identifier: Name***	*Con#1 - Opt#1:* ***PubSub (Apache Kafka)***
	Description	*The data is collected by allowing the sensors to publish messages containing their readings to specific topics, several clients (dedicated to different aspects of the system) can subscribe to these topics in order to retrieve the data.*
	Status	***decided***
	Relationship(s)	-
	Evaluation	*Cr#1: Kafka guarantees that every message that is published is then received by the subscriber (sooner or later).* *Cr#2: Kafka implements several fault-tolerance techniques such as:* • *in case of a cluster fails another one takes its place, with all the updated data, every member of the cluster has all the replicated/up-to-date data;* • *data can be saved for an arbitrary amount of time on the brokers;* • *for a topic with replication factor N, it will tolerate up to N-1 server failures without losing any records committed to the log;* • *Kafka replicates the log for each topic's partitions across a configurable number of servers. This allows automatic failover to these replicas when a server in the cluster fails so messages remain available in the presence of failures.* • *…* *Cr#3: Kafka allows to transmit order of millions of messages per second (that is much more than the required 40.000/hour).* *Cr#4: Kafka allows our system to have great scalability: if we need to add more sensors/actuators we just need to install them and let them publish their messages to the dedicated topic.*
	Rationale of decision	*We* ***chose*** *this option as it satisfies all the criteria and it provides out-of-the-box dependability features that would have been manually implemented otherwise.*
	Identifier: Name	*Con#1 - Opt#2:* ***PubSub (plain MQTT)***
	Description	*The data is collected by allowing the sensors to publish messages containing their readings to specific topics, several clients (dedicated to different aspects of the system) can subscribe to these topics in order to retrieve the data.*
	Status	***rejected***
	Relationship(s)	-
	Evaluation	*Cr#1: MQTT guarantees that every message that is published is then received by the subscriber (sooner or later).* *Cr#2: MQTT as a machine to machine protocol lacks of dedicated fault-tolerance techniques (it requires wrapping).* *Cr#3: MQTT allows to transmit order of millions of messages per second (that is much more than the required 40.000/hour).* *Cr#4: MQTT allows our system to have a good enough scalability: if we need to add more sensors/actuators we just need to install them and let them publish their messages to the dedicated topic.*
	Rationale of decision	*We* ***rejected*** *this option because it requires wrapping to deliver fault-tolerance.*

	Identifier: Name	*Con#1 - Opt#3:* ***asynchronous task queue/event based (Celery)***
	Description	*Celery it's a task queue with focus on real-time processing, while also supporting task scheduling. It is based on MQTT protocol it communicates via messages, usually using a broker to mediate between clients and workers. The data are sent to the workers, which triggers tasks that will store/make computations of the received data.*
	Status	***rejected***
	Relationship(s)	-
	Evaluation	*Cr#1: The tasks are guaranteed to be executed sooner or later after the message is sent* *Cr#2: Celery does not implement fault tolerance techniques, so it would be necessary to manually develop them from scratch.* *Cr#3: Celery allows for millions of tasks per second (that is much more than the required 40.000/hour).* *Cr#4: Celery allows to add workers as needed so to achieve good enough scalability.*
	Rationale of decision	*We* ***rejected*** *this option because it not satisfies Cr#2, even if it provides greater performances with respect the other solutions, but in our instance performance is not an important requirement as fault tolerance and dependability in general.*

Concern (Identifier: Description)		*Con#2: How can we store and organize the data?*
Ranking criteria (Identifier: Name)		*Cr#1: Data organization - the data must be easily organisable* *Cr#2: Scalability - the system must be easily scalable (by means of amount of incoming data)* *Cr#3: Performance - amount of data that can be stored/how fast can we retrieve-insert them*
Options	***Identifier: Name***	*Con#2 - Opt#1:* ***NoSQL DB + relational DB***
	Description	*The sensors readings are stored in the NoSQL DB, the data regarding the organization of the system and the authorizations are stored in the relational DB.*
	Status	***decided***
	Relationship(s)	-
	Evaluation	*Cr#1: The use of a relational DB allows to easily to store the data regarding the system structure.* *Cr#2: The use of a NoSQL DB allows us to store billions of records without performance impacts.* *Cr#3: The NoSQL DB delivers noticeable performance at massive scale: millions of ops/sec, 100s of billions of records, huge amounts of data. Also, splitting the load to two different DBs allows us to avoid further overhead that would derive by using only a DB (we can query the relational DB without impacting on the NoSQL one).*
	Rationale of decision	*We* ***chose*** *this option as it optimally satisfies all the criteria.*
	Identifier: Name	*Con#2 - Opt#2:* ***NoSQL DB***
	Description	*Both sensor's readings and system structure data is stored on the NoSQL DB.*
	Status	***rejected***
	Relationship(s)	-
	Evaluation	*Cr#1: Storing strongly related data in a NoSQL environment is not always easy.* *Cr#2: The use of a NoSQL DB allows us to store billions of records without performance impacts.* *Cr#3: The NoSQL DB delivers noticeable performance at massive scale: millions of ops/sec, 100s of billions of records, huge amounts of data; but all the load is assigned to the NoSQL DB.*
	Rationale of decision	*We* ***rejected*** *this option because it not optimally satisfies the Cr#1.*
	Identifier: Name	*Con#2 - Opt#3:* ***Relational DB***
	Description	*Both sensor's readings and system structure data is stored on the Relational DB.*
	Status	***rejected***
	Relationship(s)	-
	Evaluation	*Cr#1: The use of a Relational DB allows to easily to store the data regarding the system structure.* *Cr#2: The use of the Relational DB does not allow us to easily store huge amount of data, at least not without performance impact. In our system, there is an expected amount of 423 millions of records that would impact the performances if stored on the relational DB, plus we plan to perform analysis on this data and relational DB are not suited for this.* *Cr#3: The Relational DB usually does not perform well with high amount/volume of data/traffic.*
	Rationale of decision	*We* ***rejected*** *this option because it not satisfies the Cr#2 and Cr#3.*

Concern (Identifier: Description)		*Con#3: Where can we store the data? (in our instance)*
Ranking criteria (Identifier: Name)		*Cr#1: Privacy/Security* *Cr#2: Dependability - the data must be easily organisable* *Cr#3: Costs*
Options	***Identifier: Name***	*Con#3 - Opt#1:* ***Everything in local storage***
	Description	*All the data are stored in the UnivAQ's servers.*
	Status	***decided***
	Relationship(s)	-
	Evaluation	*Cr#1: The data is stored in a private and closed environment.* *Cr#2: The dependability depends on the dependability of the UnivAQ's infrastructure.* *Cr#3: The costs are near to 0 as we are using an existing infrastructure.*
	Rationale of decision	*We* ***chose*** *this option as it optimally satisfies all the criteria: we have low costs, we are certain that the data is only accessed by us and we have a good enough level of dependability.*
	Identifier: Name	*Con#3 - Opt#2:* ***Everything in the cloud***
	Description	*All the data are stored in the cloud.*
	Status	***rejected***
	Relationship(s)	-
	Evaluation	*Cr#1: Data is located in a not directly controlled environment and it is managed by third parties.* *Cr#2: Maximum level of dependability assured by the cloud provider but it is strongly dependant to the availability of an active internet connection (in case of disasters we could not have an active internet connection).* *Cr#3: The costs could be high with respect to the amount of data we want to store.*
	Rationale of decision	*We* ***rejected*** *this option because it does not optimally satisfy Cr#1, Cr#2 and Cr#3.*
	Identifier: Name	*Con#3 - Opt#3:* ***Part of the data in local storage and part on the cloud***
	Description	*Some of the data is stored in the UnivAQ's infrastructure and some is stored in the cloud.*
	Status	***rejected***
	Relationship(s)	-
	Evaluation	*Inherits the problems from the evaluation of Con#3 - Opt#2*
	Rationale of decision	*We* ***rejected*** *this option because it not optimally satisfies Cr#1, Cr#2 and Cr#3.*

Concern (Identifier: Description)		*Con#4: Which programming language should we use?*
Ranking criteria (Identifier: Name)		*Cr#1: Performance* *Cr#2: Support* *Cr#3: Speed of development*
Options	***Identifier: Name***	*Con#4 - Opt#1: **Java***
	Description	*The components are developed using Java*
	Status	***decided***
	Relationship(s)	*Con#1*
	Evaluation	*Cr#1: Java is arguably one of the most performant programming languages available.* *Cr#2: Kafka is developed in Java and provides official APIs and documentation for Java.* *Cr#3: Java is a pretty verbose language and development can be tedious and slow, even if several frameworks (such as Spring - for REST APIs) are able to significantly increase the speed of development.*
	Rationale of decision	*We **chose** this option mostly because we have official APIs and plenty of documentation, plus Java is totally portable and in an IOT settings it's a relevant advantage.*
	Identifier: Name	*Con#4 - Opt#2: **Python***
	Description	*The components are developed using Python*
	Status	***rejected***
	Relationship(s)	*Con#1*
	Evaluation	*Cr#1: Python is recognized to be one of the slowest programming languages [9].* *Cr#2: There are not official APIs for Kafka, only community developed ones.* *Cr#3: Development in Python is incredibly fast, what is done with tens of lines of code in other programming languages can be done with a few lines in Python.*
	Rationale of decision	*We **rejected** this option because even if we are able to produce prototypes in a faster way we have not the performance of other languages and we cannot use official APIs.*

From Architecture to Code

Implementation - Storing service

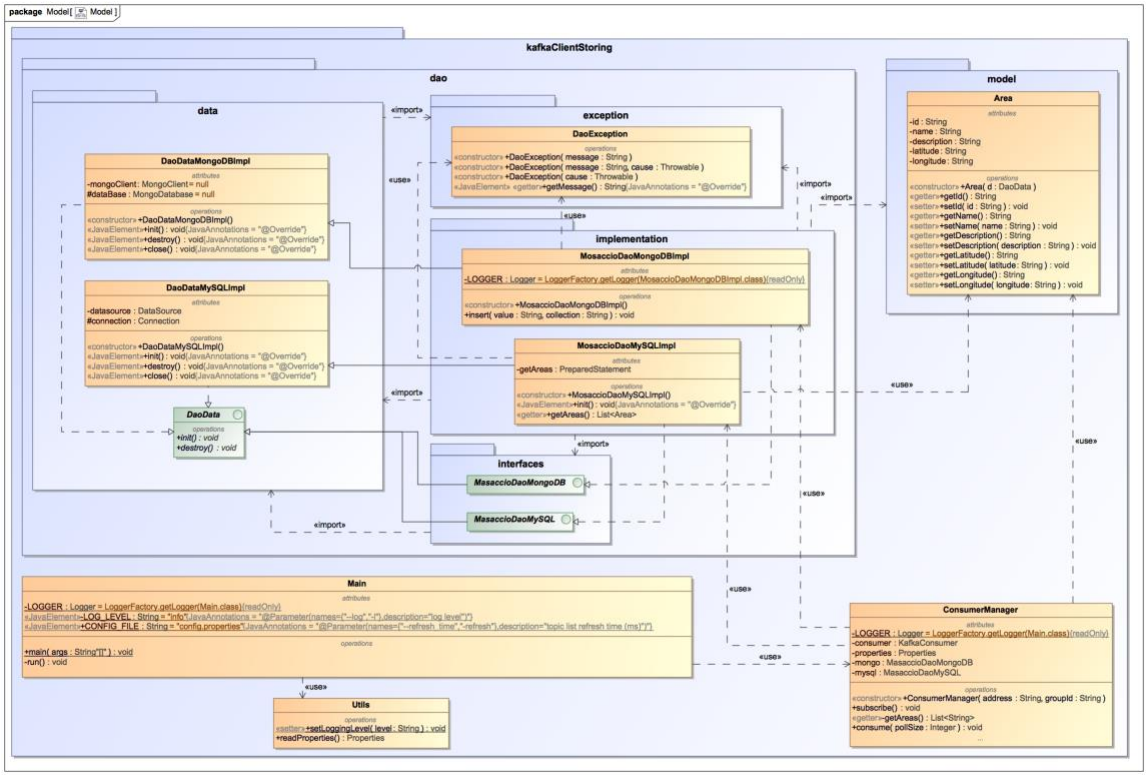
The storing process is realized by the components that have been exposed in the previous sequence diagram.

A demo video that shows the execution can be found at this link: https://youtu.be/RT7HMrQBuiI
In the showed execution there are 3 machines:

- Machine 1 hosts the mysql relational database and the NoSQL MongoDB database
- Machine 2 hosts the Kafka Client – Storing and the Kafka Cluster
- Machine 3 simulates 4 sensors with their Sensor Managers

A more detailed description can be found directly in the video annotations/description and in the sequence diagram provided in the previous sections.

We now show the structure of the implemented components:
the following class diagram describes the composition of the **Kafka Client - Storing** component:



The component is composed by several sub-packages such as:

- **dao:** to implement the communication with both the databases it has been used the DAO (Data Access Object) design pattern. It makes available interfaces that allow to map the business logic calls to the persistent data model, it is composed by:

  - **dao.data:** contains the classes who implements the connection to the dbs using connection pooling techniques, when possible (mongodb, for instance, do not allow to use connection pooling as it uses its own protocol).
  - **dao.exception:** contains the implementation of personalized exceptions types.
  - **dao.interfaces:** contains the interfaces that will be implemented by the classes inside the **dao.implementation** sub-package, they allow to define certain fixed behaviors that these classes must follow.
  - **dao.implementation:** contains the classes who implement the interfaces inside the **dao.interfaces** sub-package. These classes are used to physically interact with the databases (the perform the queries and return the results).

- **model:** this sub-package contains the representation of the database entities, this component (Kafka Client - Storing) only need to interact with one entity: **Areas** (please, check the ER schema for more details). So, in this sub-package we have the class Area which represent the corresponding entity on the relational database.

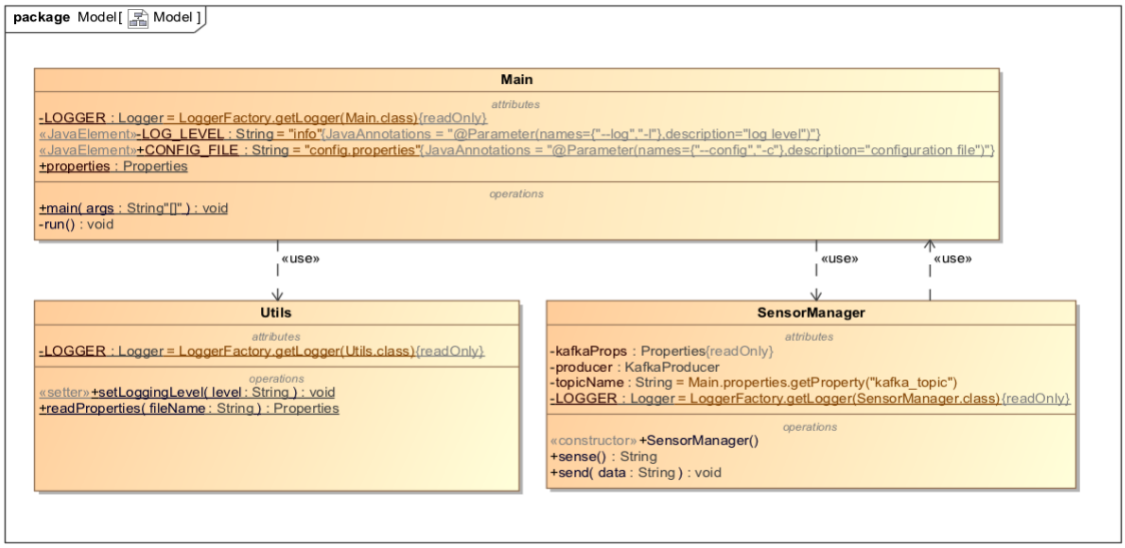
The class **ConsumerManager** contains the methods that allow to consume the messages published on the area topics that are retrieved (using the DAO infrastructure) from the relational database.
The **Utils** class contains general purpose static methods.
The **Main** class contains the initialization of the **properties** object that allows to parse properties files that can be used to set configuration variables such as the address of the kafka cluster, the credential to access the databases etc.
It also contains the instantiation of the **ConsumerManager** object.

The flow of the computation follows what has been described on the sequence diagram.
Now, we better specify the behavior of the **Kafka Client - Storing** component (**:**

- first, the instantiation of the **ConsumerManager** object is followed by the fetch of the area topics names from the relational database (using the DAO infrastructure)
- subsequently the client subscribes to all of them (this happens inside the method *subscribe()).*
- now, the client is put in listen mode with the method *consume()*, this allow the client to listen for new messages on **all** the available topics.
- when a message is received its payload is stored on the Mongo database (using the DAO infrastructure).
- this cycle is repeated every X seconds (the amount can be changed): ***this allow the system to adapt itself to newly added area topics***, in fact, when the cycle restarts, the client fetches the list of the topics and it subscribes to them again, so there is no need of a manual restart; plus, thanks to kafka every message that has been not received because of any kind of unexpected downtime is safely stored in the cluster and it will be retrieved as soon as the client (Kafka Client - Storing) comes back online.

The most important aspect of this implementation is that ***it is enough to run multiple instances of the application to have an automatic load-balance among the instances with respect to the topics/partition assignment***, plus every instance can be executed on a totally different machine in a totally different geographic area. It is enough to provide the address of the cluster and the databases through command line arguments.

The following class diagram describes the composition of the **Sensor Manager** component.



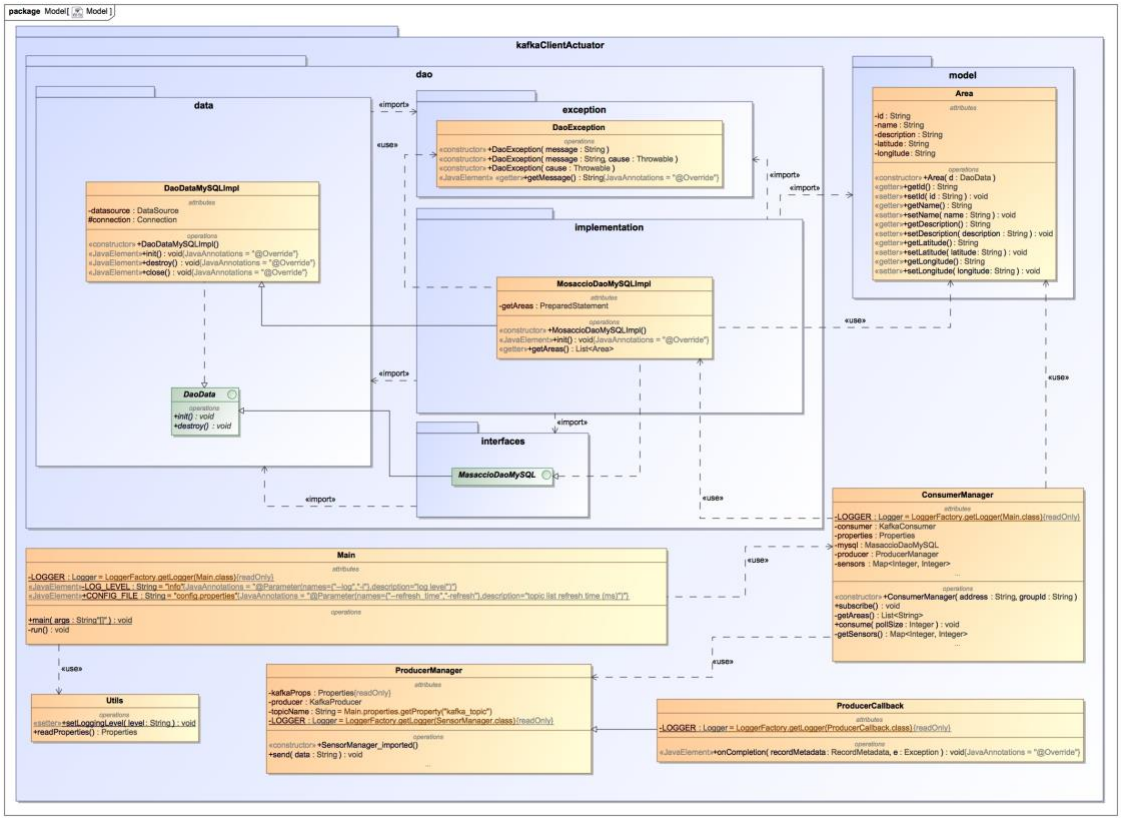
The component is composed by the following classes:

- **Main:** it is responsible to initialize the **SensorManager** object and to run it.
- **Utils:** it contains some useful functions used by the Main class (such as the function to change the logging level and the function to read the configuration file).
- **SensorManager:** it contains the function to **sense the world** (this function will be the function that will communicate with the sensor: now the reading of the sensor is simulated by generating a random alphanumerical string) and the function that is responsible to the publishing of the messages to the respective Kafka topic; each message is a string representing a .json file containing the id of the sensor, the reading and the timestamp.

Implementation - Actuation service

The video demo of the implemented service can be found here: https://youtu.be/YfUbq6JpVns
The service is realized by the components that have been introduced in the sequence diagram. We now describe how these components have been realized.

Kafka Client - Actuator



The component is composed by the following sub-packages such as:

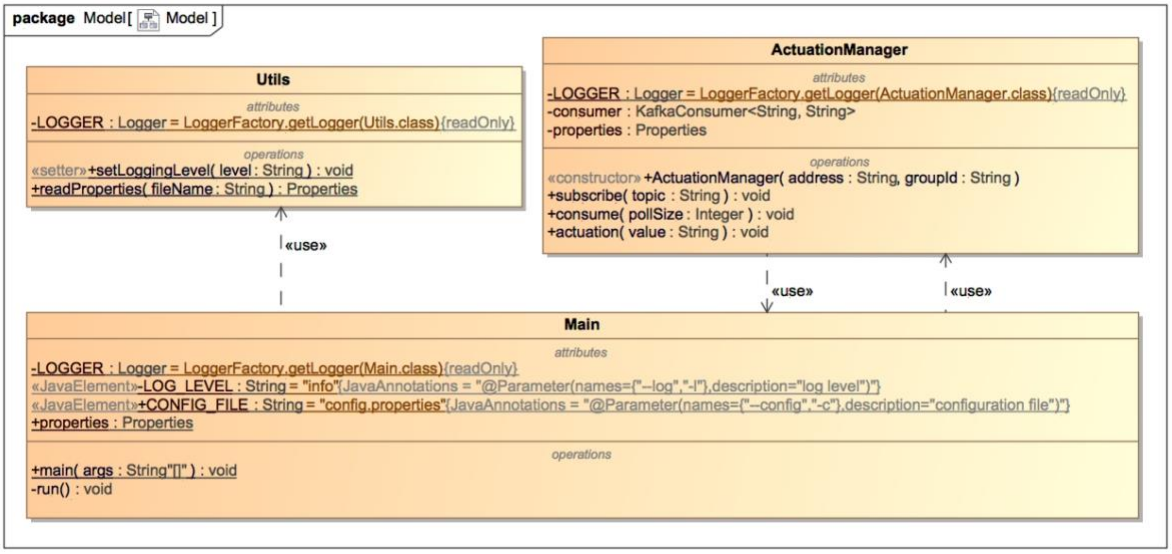
- **dao**: that is equal to the **Kafka Client - Storing** class diagram (lacks of only the MongoDB part that isn't needed for this component).
- **model**: that is equal to the **Kafka Client - Storing** class diagram.

The class **ConsumerManager** contains the methods that allow to consume the messages published on the **Area Topics** that are retrieved (using the DAO infrastructure) from the relational database (following the same scheme described in the **Kafka Client - Storing**).
The difference is in that this component (**Kafka Client - Actuator**) instead of storing the data as the **Kafka Client - Storing**, it produces, through the **ProducerManager** class, a triggering message for the actuator that is related to the sensor that initially sent the message.
The **ProducerManager** class contains the methods that allow to produce messages in order to trigger the correspondent Actuator. The **ProducerCallback** is a **sub-class** of the **ProducerManager** and allow us to produce messages in asynchronous way.
The **ProducerManager** class follows the same scheme as the **SensorManager** class (described in the previous deliverable).

The Utils class contains general purpose static methods.

The Main class contains the initialization of the properties object that allows to parse properties files that can be used to set configuration variables such as the address of the Kafka Cluster, the credential to access the databases etc.
It also contains the instantiation of the ConsumerManager object and the main loop.

Actuation Manager



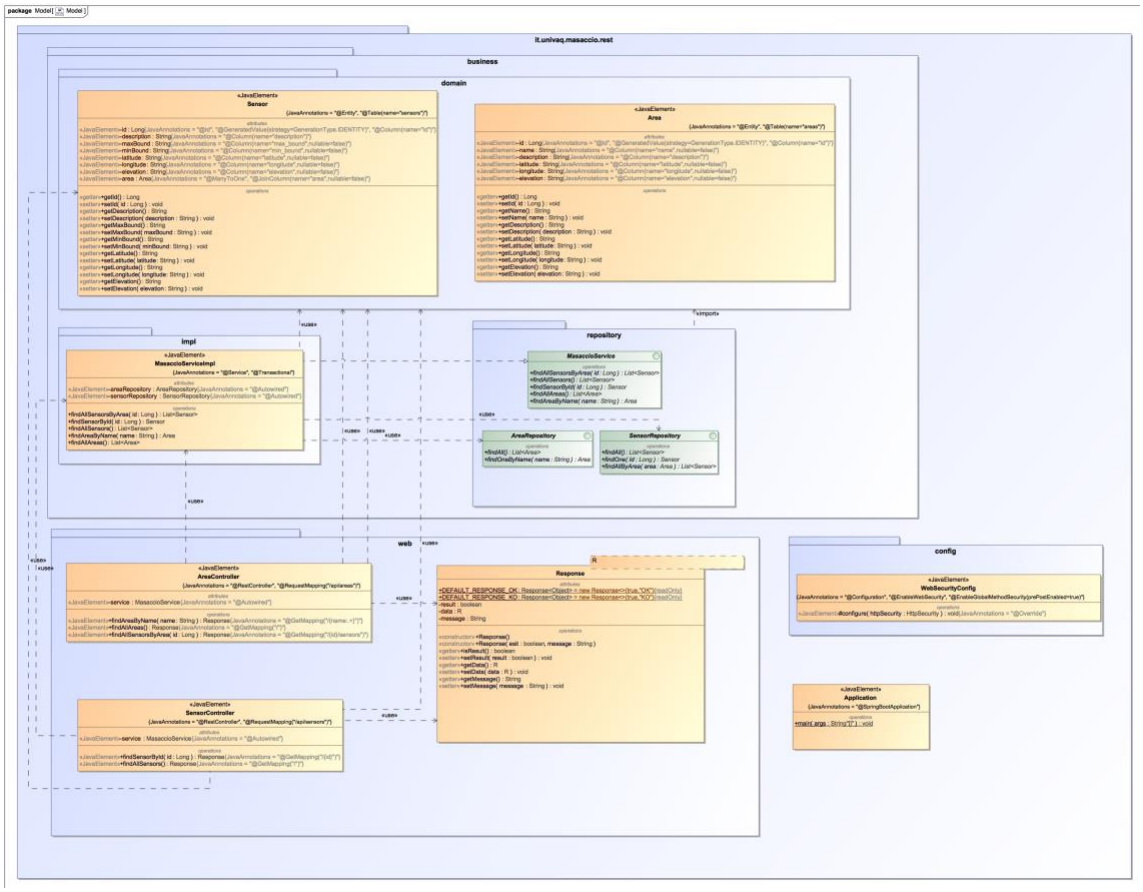
It follows the same configuration as the SensorManager described in the previous deliverable but instead of producing messages, it consumes messages and triggers the related actuator (physical device). It is composed by the following classes:

- Utils: contains general purpose static methods.
- ActuationManager: It contains the methods subscribe() and consume(), (that are the same that are used by the Kafka Client - Storing and Kafka Client - Actuator) used to subscribe and consume messages published in the Kafka Cluster. In this component, there is no need to retrieve data from the relational database because the topic is only one (the one related to the physical actuator) and it is provided as a parameter in the component's configuration file.
  It also contains the method actuation() that simulates the actuation of the physical device.
- Main: is the class that initialize the component and reads the properties from the configuration file, it is also responsible for the call of the ActuationManager methods.

Implementation - Visualization service

The video demo of the implemented service can be found here: https://youtu.be/wh2H0fjx1bE
In the execution there are 3 sensors that are associated with the area a1.1, the sensors publish their messages to their area topic (just like in the other services). The **Kafka Client - Visualization** listens to all the area topic and each time it consumes a record it forwards it to the respective **websocket** to which the **Dashboard** is listening to.
The **Dashboard** also uses the **REST Server** to retrieve data from the database.

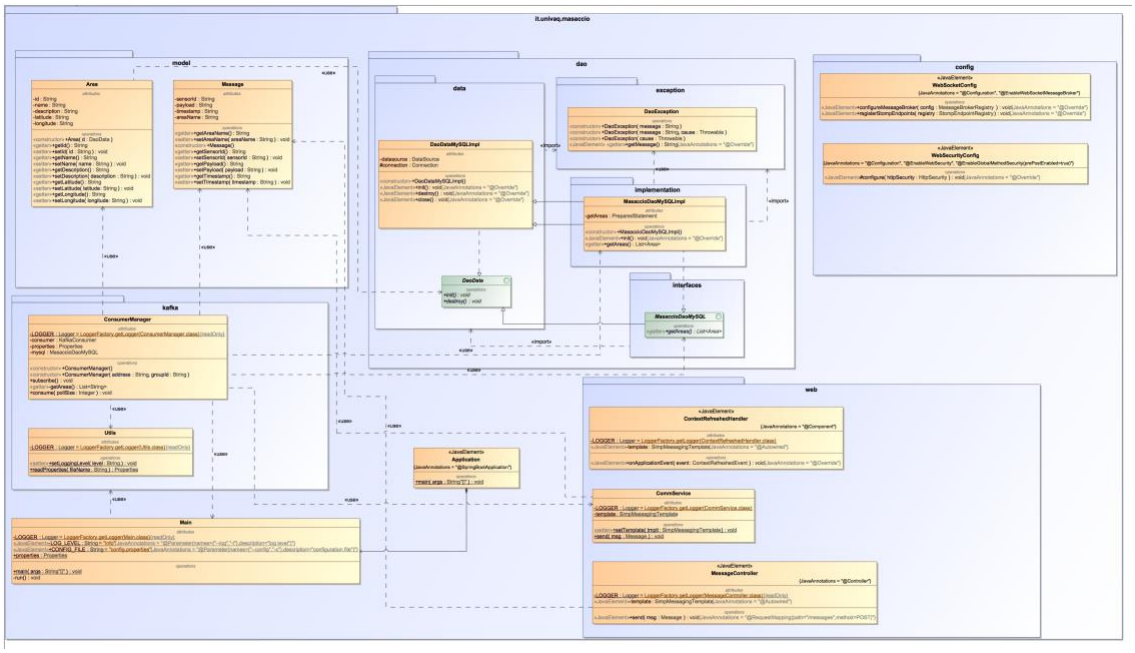
REST Server



The **REST Server** has been implemented using the **Spring Framework** (in particular Spring Boot).
The **Spring Framework** allow to quickly develop REST APIs (among other things) in an efficient and clean way.
The class diagram reflects the standard organization of a Spring application that is a classical MVC pattern.
The **web** sub-package contains the controllers, these are the ones that expose the services to the clients.
Each controller returns to the client an instance of the **Response** class.
The controllers invoke the services that are implemented by the **MasaccioServiceImpl** class in the **business.impl** sub-package.

These services use the methods that are defined by the interfaces in the **business.repository** sub-package. These interfaces are used by **Spring** to understand which methods to implement. These implemented methods are then used to effectively communicate with the database.
The **business.domain** sub-package contains the java representation of the entities on the database.
The **config** sub-package contains the configuration class of the application.

Kafka – Client Visualization



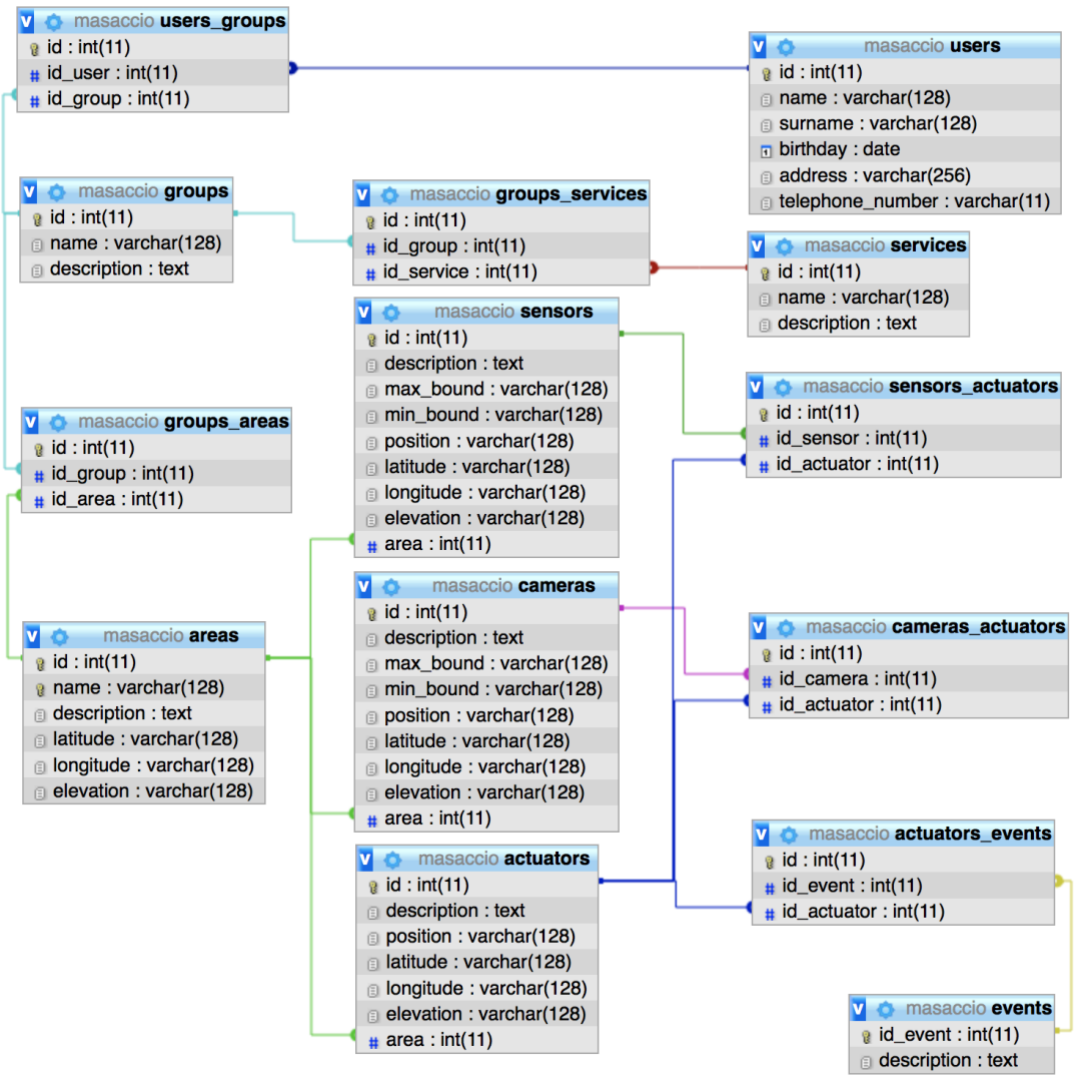
Just like the **REST Server**, the **Kafka Client - Visualization** uses the **Spring Framework;** in this case it is used to realize the **websockets** that are used to communicate with the **Dashboard**.

The **dao** sub-package is the same that has been used in the other implemented Kafka Clients.
The **web** sub-package contains:

- **MessageController**, that is the controller that wraps the emission of the message to the **websockets**.
- **CommService,** that is the class that implements the **send()** method that is responsible to effectively send the message to the **websockets.**
- **ContextRefreshedHandler**, that is an event listener used to refresh the Spring resources when an event occurs.

The **model** sub-package contains the java representation of the entities described on the database (in this implementation only the "area" entity has been used) and the **Message** class who wraps the outgoing messages.
The **config** sub-package contains the configuration classes of the application.
The **kafka** sub-package contains the classes used to consume the messages published on the cluster (in particular **ConsumerManager** and **Utils,** that have been described in the other clients). In this client, when a Kafka message is consumed a send() is performed to forward the message to the respective **websocket**, as described in the sequence diagram.

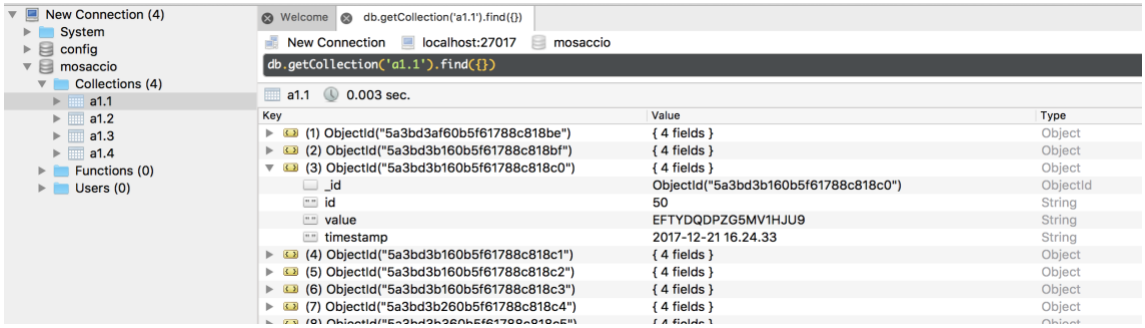
The **relational database** is structured as follows (we are using mysql):



- The **users** table contains all the data about people that have a profile on the system (we are talking about authorized people). We store the name, surname, birthday, address, telephone's number and we distinguish every registered person with a unique id.
- The **groups** table contains all the info about the group of peoples (or categories) that have responsibility and special permission in some kind of area.
- The **services** table contains all the services that can be accessed by authorized groups.
- The **users_groups** table contains different pairs of user's id and group's id and identifies which person belong to a determinate group.
- The **groups_services** table contains different pairs of group's id and service's id and represent which services are available for a specific group.
- The **groups_areas** table is used to store the ids of groups that have some kind of authorization in a specific area, identified by the respective id.
- The **areas** table is used to store all the data about the different areas that the system monitors.

- The **cameras** table contains all the data about every camera that is deployed in the system. Indeed, in this table there is a field that contains the id of the area in which the camera has been positioned.
- The **sensors** table contains all the data about every sensor that we have used for each area (this table contains also a field with the id of the area in which the sensor has been positioned).
- The **actuators** table contains all the data about every actuator that we have used for each area (also this table have a field that contains the id of the area in which the actuators has been positioned).
- The **events** table contains all the information about the events that are generated in the system’s areas.
- The **sensors_actuators** table contains the information about the relation between sensors and actuators, the single row of the table says which sensor triggers a certain actuator.
- The **cameras_actuators** table contains the information about the relation between cameras and actuators, the single row of the table says which camera triggers a certain actuator.
- The **actuators_events** table contains the data concerning the relation between events and actuators, in particular we want to keep a log in which we store which actuator has been activated for a certain event.

The NoSQL database (**MongoDB)** is structured as follows:



The MongoDB database works with databases and collections, each database is composed by different collections.
We are using a collection-per-topic approach, so we store the data of the sensors belonging to the area X to the collection named X.
In our instance, there’s a database called “**masaccio**”. In this database, there are three main folders.

Collections, that contains all the collections that the system generates (a collection for each area/topic).

Every collection contains a set of .json documents that are composed by the data that the system receives from sensors and cameras plus their ids and timestamps (it also contains the internal id of the document itself, used by Mongo and called “_id”).

For example, in the figure we show the set of documents that characterize the area **a1.1**. We show also the third document of this set, that contain all the pair “key-value” that corresponds to a reading performed by the sensor with id=50, the actual reading and the timestamp.

Functions and **Users** are default collections that are generated when the database is created.

Performance Analysis

To validate our architecture, we had to check the performance of the system. After some tests (on some cheap laptops) we can assert that our system can easily:

kind of operation	# of topics	# of messages per topic	# of total messages	time (seconds)	kind of message	*messages/second*
Publish (Produce)	6	40.000	240.000	13.8170	String	*about 15.644*
Subscribe (Consume)	6	40.000	240.000	15.3411	String	
Store (from String to .json)	-	-	240.000	real-time/ asynchronous	.json	

This test was made on a network composed by three laptops: this implies some small network delay. The storage on the NoSQL DB of this prototype is synchronous: the *Kafka Client - Storing* subscribes to the topics, consumes data and then it stores the records on the database.
We can assert that the numbers we got are much higher with respect to the customer's required numbers. So, we can conclude that the system is fully capable of handling the requested amount of data traffic.

UPDATE: after refining the implementations we performed further tests.
Proofs of the results can be found in the *"implementation/tests_screenshots"* folder.

kind of operation	# of topics	# of messages per topic	# of total messages	time (seconds)	kind of message	*messages/second*
Publish (Produce)	1.000	500	500.000	11.6550	String	*about 42.424*
Subscribe (Consume)	1.000	500	500.000	11.7856	String	
Store (from String to .json)	-	-	500.000	real-time/ asynchronous	.json	

kind of operation	# of topics	# of messages per topic	# of total messages	time (seconds)	kind of message	*messages/second*
Publish (Produce)	1.000	1.000	1.000.000	14.6767	String	*about 66.333*
Subscribe (Consume)	1.000	1.000	1.000.000	15.0754	String	
Store (from String to .json)	-	-	1.000.000	real-time/ asynchronous	.json	

Summary

In our instance, we want to monitor and analyze UnivAQ's buildings.
Our architecture is based on a PubSub pattern, implemented using the Kafka framework.
The data concerning the system's organization is stored in a relational database while the sensed data is stored in a NoSQL MongoDB database.

This approach, along with features provided by Kafka, allow the system to have a great level of dependability such as: if a producer loses the connection to the cluster it will wait for the connection to come back online without crashing or losing messages. If a consuming client loses the connection it will simply wait for the cluster to come back online and it will resume the consumption from where it left.
The fault-tolerance of the cluster can be increased by adding replicas: a leader will be elected among the participant and when a component goes offline the others will proceed its work with all the up to date data.

It also provides good performance (as exposed on the previous pages we are able to sense-and-store about 40.000 - 60.000 messages per second when the requirements were referring to 40.000/hour, with the clients running on common laptops and in a wi-fi network (we expect greater performance on dedicated hardware and wired network).

All the clients can run on different machines and on different geographic areas (as demonstrated on the video-demo).

We can have an automatic load balance by simply running more instances of a client. For instance, if we run the Storing client 3 times, as each of the instances belong to the same group, the cluster will automatically assign a portion of the messages to each client, balancing the load (as each instance can run on a different machine).

This approach also provides a great level of decoupling as all the components are independent from each other.
For instance, the Storing client is not related in any way to the Visualization client or the Analysis Engine or the Actuators client.

We are also able to add new sensors and new areas simply by installing the physical device, let him publish on its topic and register the topic on the relational database: the clients will periodically check for changes and will subscribe automatically to the new topics without any kind of manual action, plus each client receives its configuration by a configuration file, this avoid changing the code if, for instance, the cluster address changes.