ETH zürich

Research Center for
Energy Networks FEN

A framework for the simulation of distributed energy systems

28.09.2021

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Agenda

1. What is the ReMaP Simulation Framework (SFW)
2. Features of the SFW
3. Basic software design of the SFW
4. Reference to already implemented “experiments” (use cases)

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1. **What is the ReMaP Simulation Framework (SFW)**
2. Features of the SFW
3. Basic software design of the SFW
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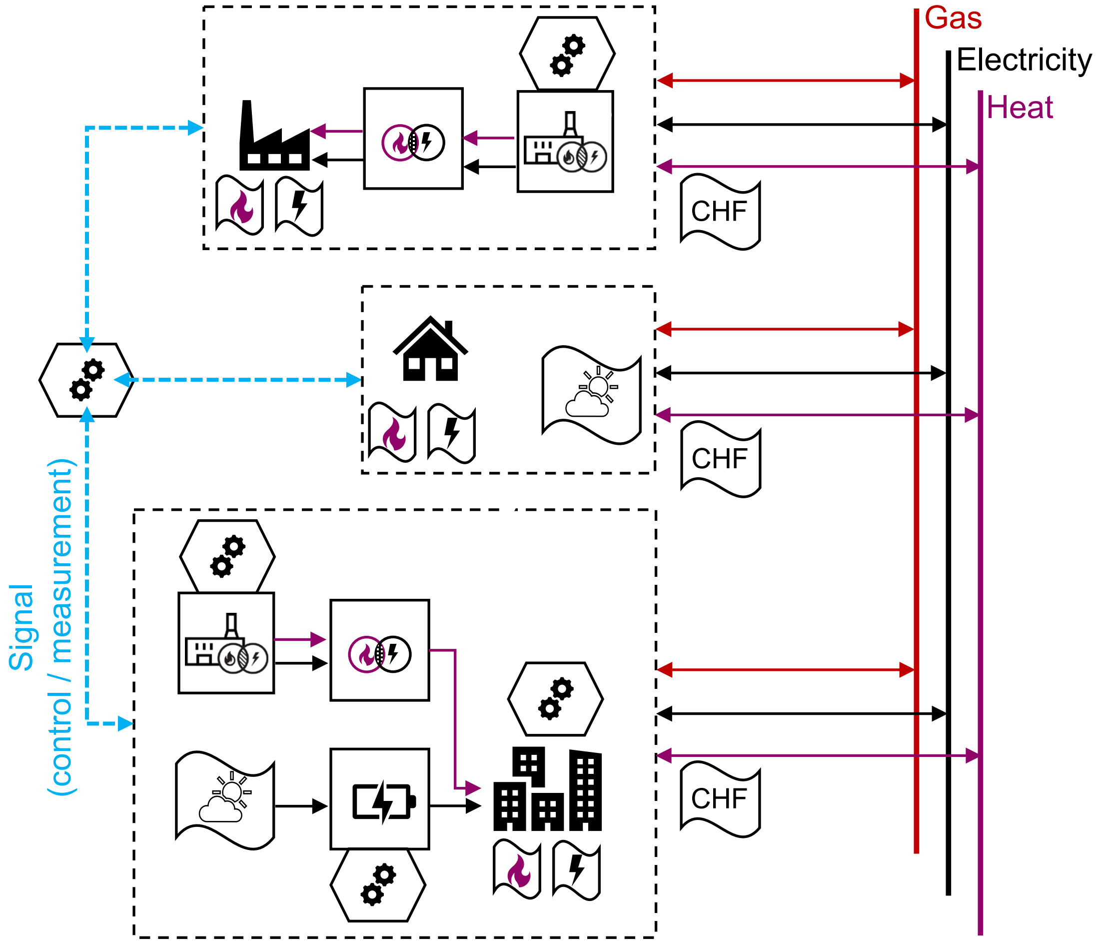
ReMaP Simulation Framework (SFW)
Representing a multi-energy-carrier district from utility to site level

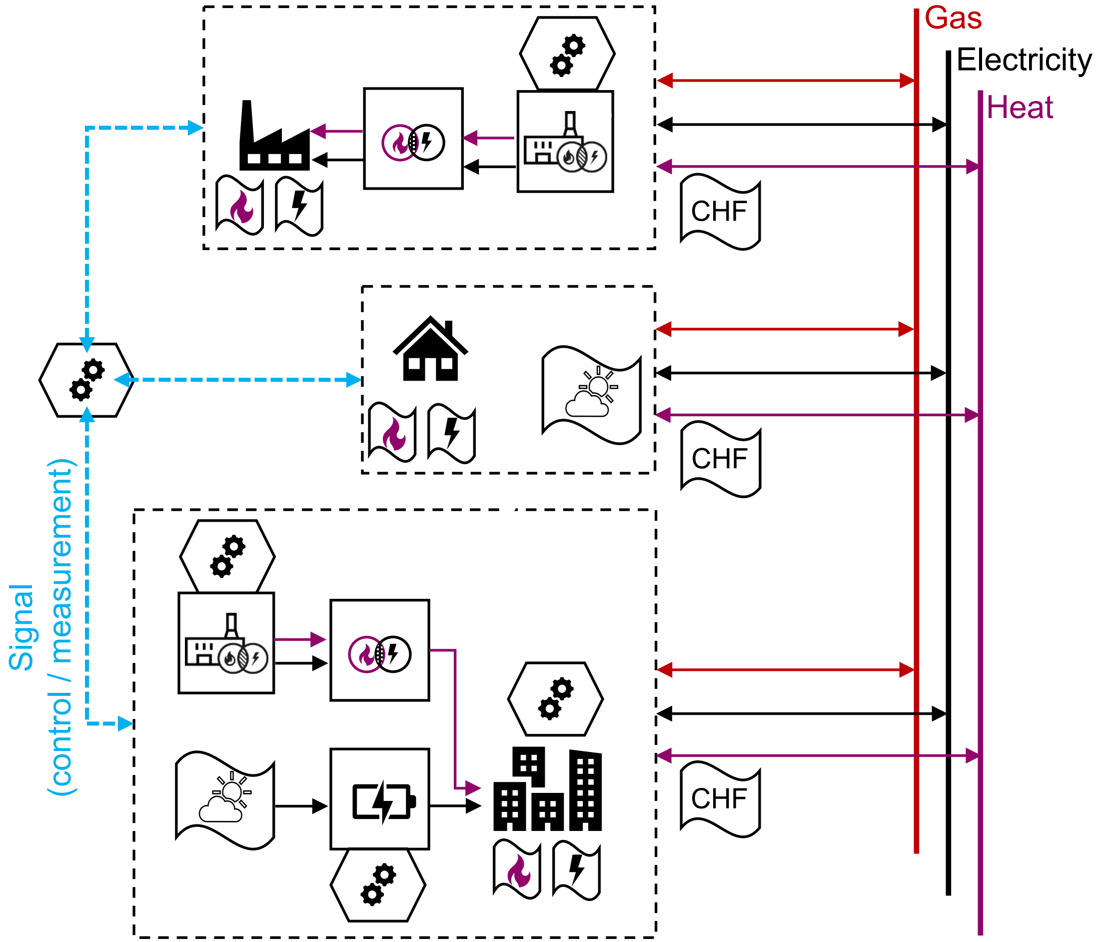


What

- A software framework allowing to simulate the operation of all energy sectors in a district
- Considers utility-level and site-level components
- Allows for simultaneous representation of a plurality of operational logic / controllers
- Time step and simulation horizon selected by the user depending on the considered case
- Can be used as part of a hardware-in-the-loop simulation

Heat pump
CHP
Battery
Solar PV
Heat demand
Electricity demand
Controller
CHF Energy price

ReMaP Simulation Framework (SFW)
Representing a multi-energy-carrier district from utility to site level



What

- A software framework allowing to simulate the operation of all energy sectors in a district
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Attributes

- Open-source python-based software
- Model library with independent hardware models and control algorithms
- Modular design; user can add his/her own models or algorithms
- Can connect to external software

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2. **Features of the SFW**
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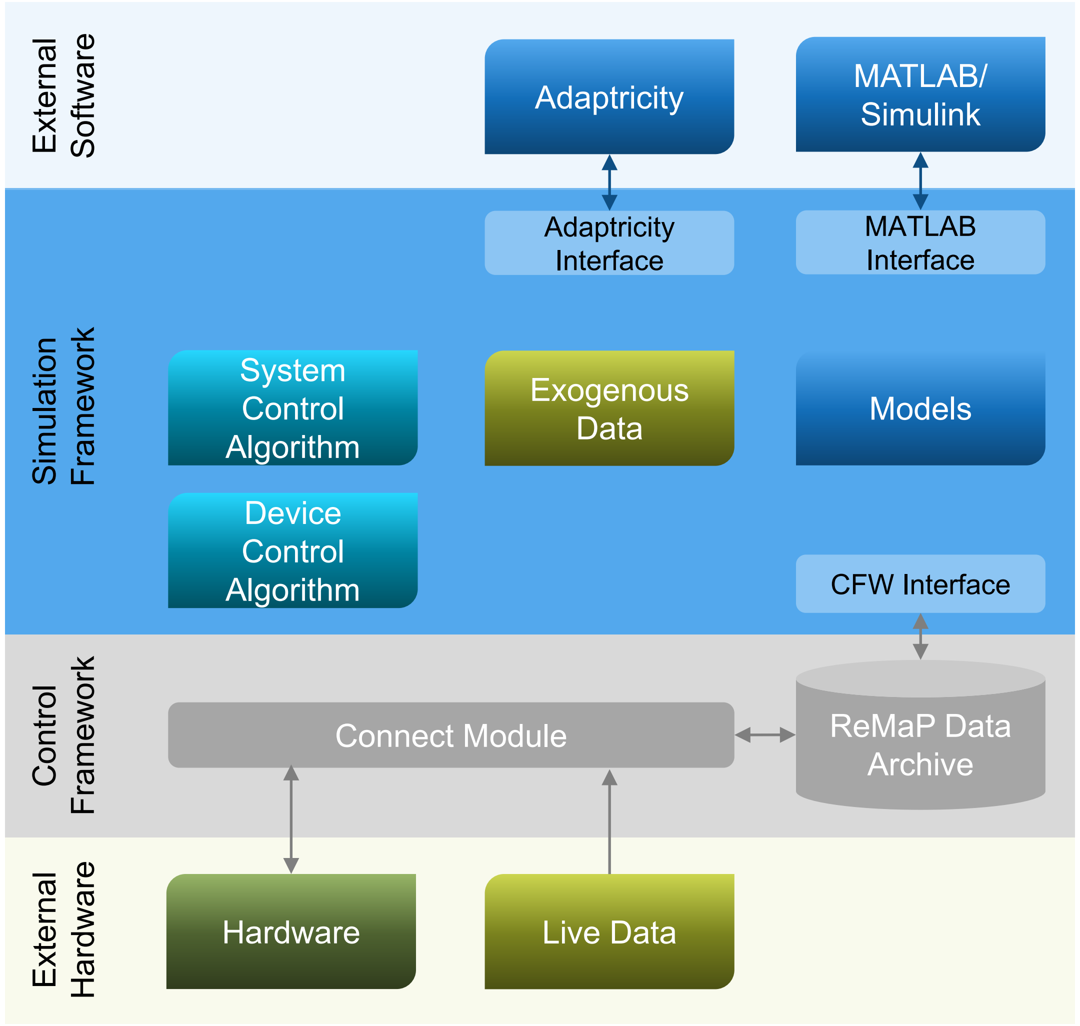
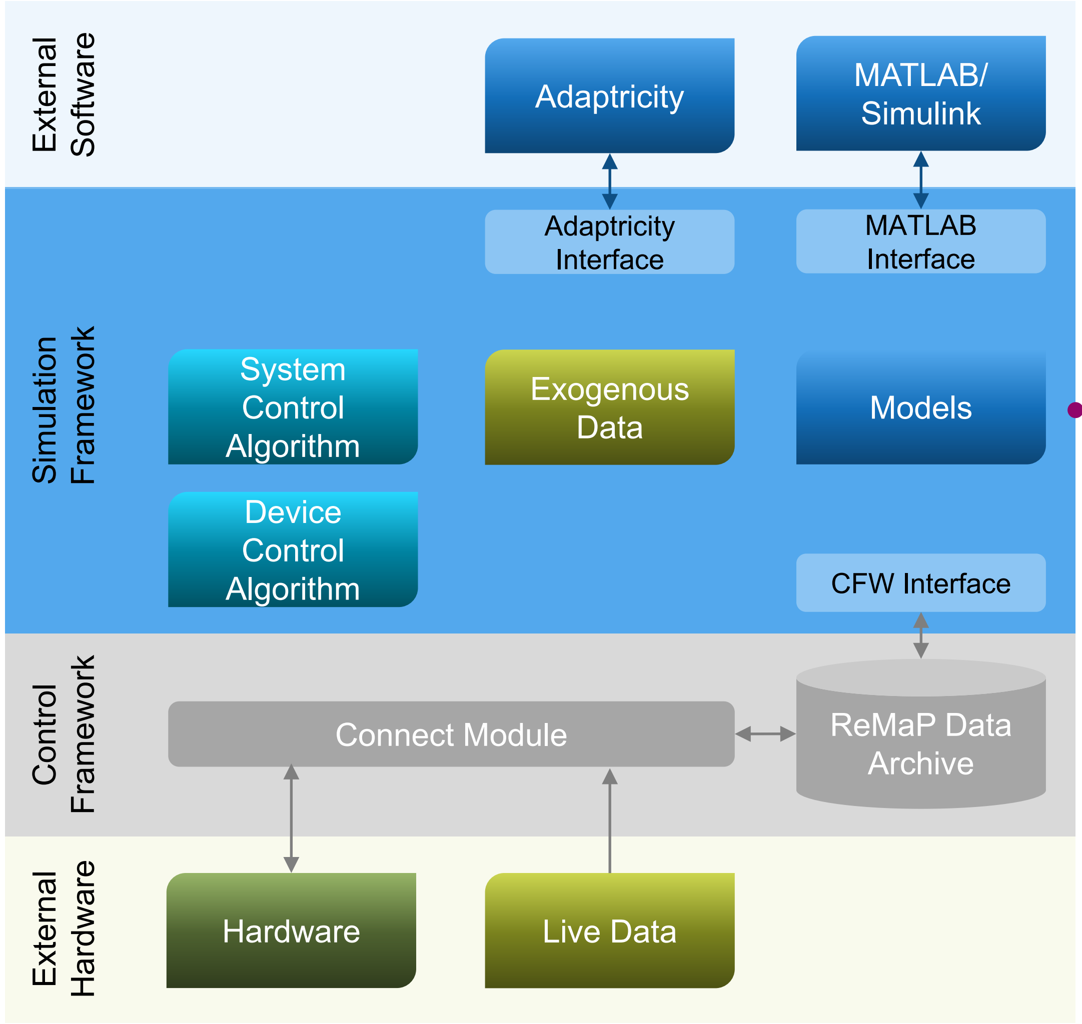
Features & Interconnections



Data Controller Model Hardware

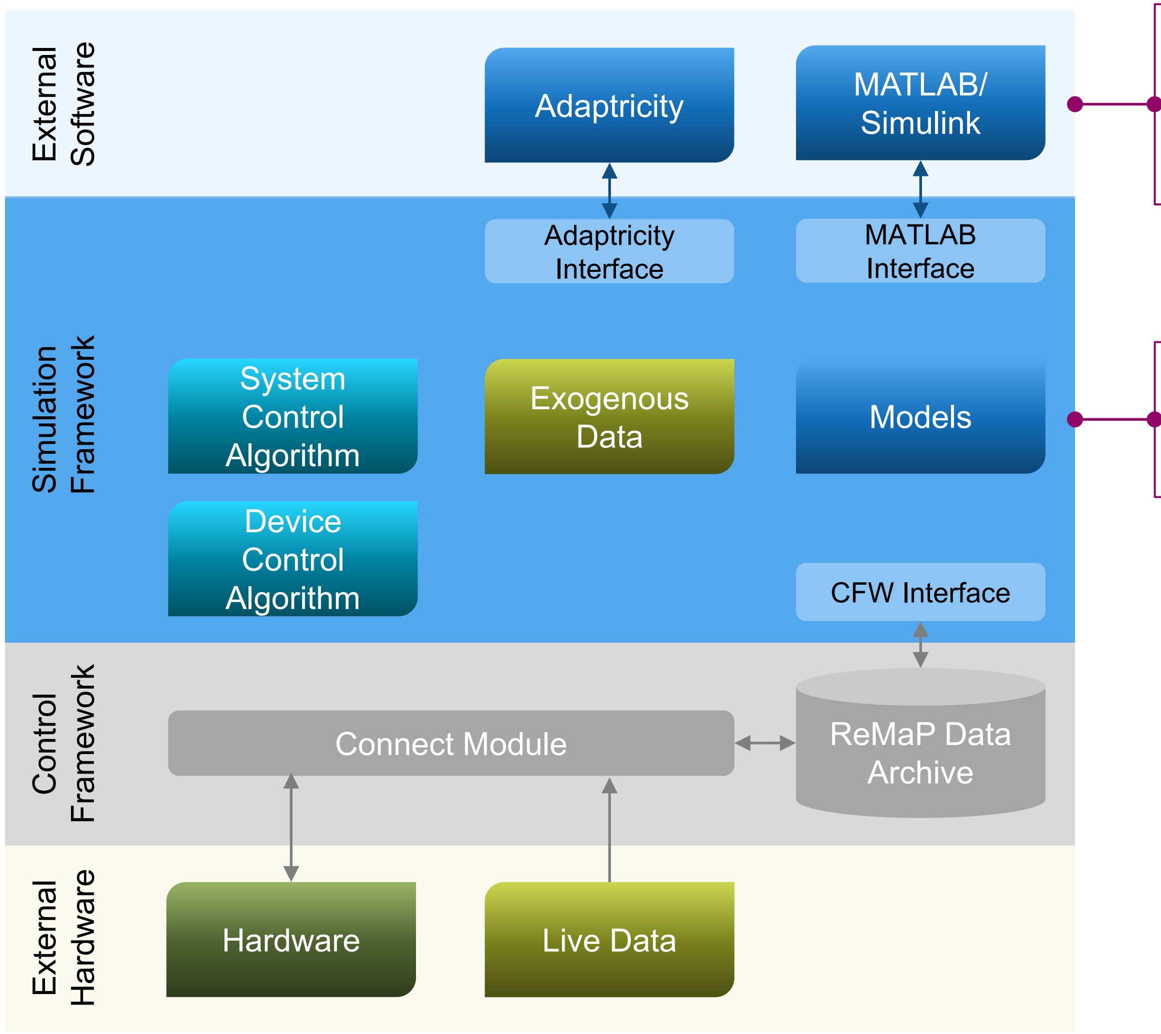
Features & Interconnections



- ✓ Plug-and-play-ability for different independent models, algorithms and data to design systems per the user's needs
- ✓ No coding required by the user

Data | Controller | Model | Hardware

Features & Interconnections



- ✓ Ability to connect to external software, where components can be represented and smoothly integrated into the simulation
- ✓ Appropriate interfaces are developed for selected cases

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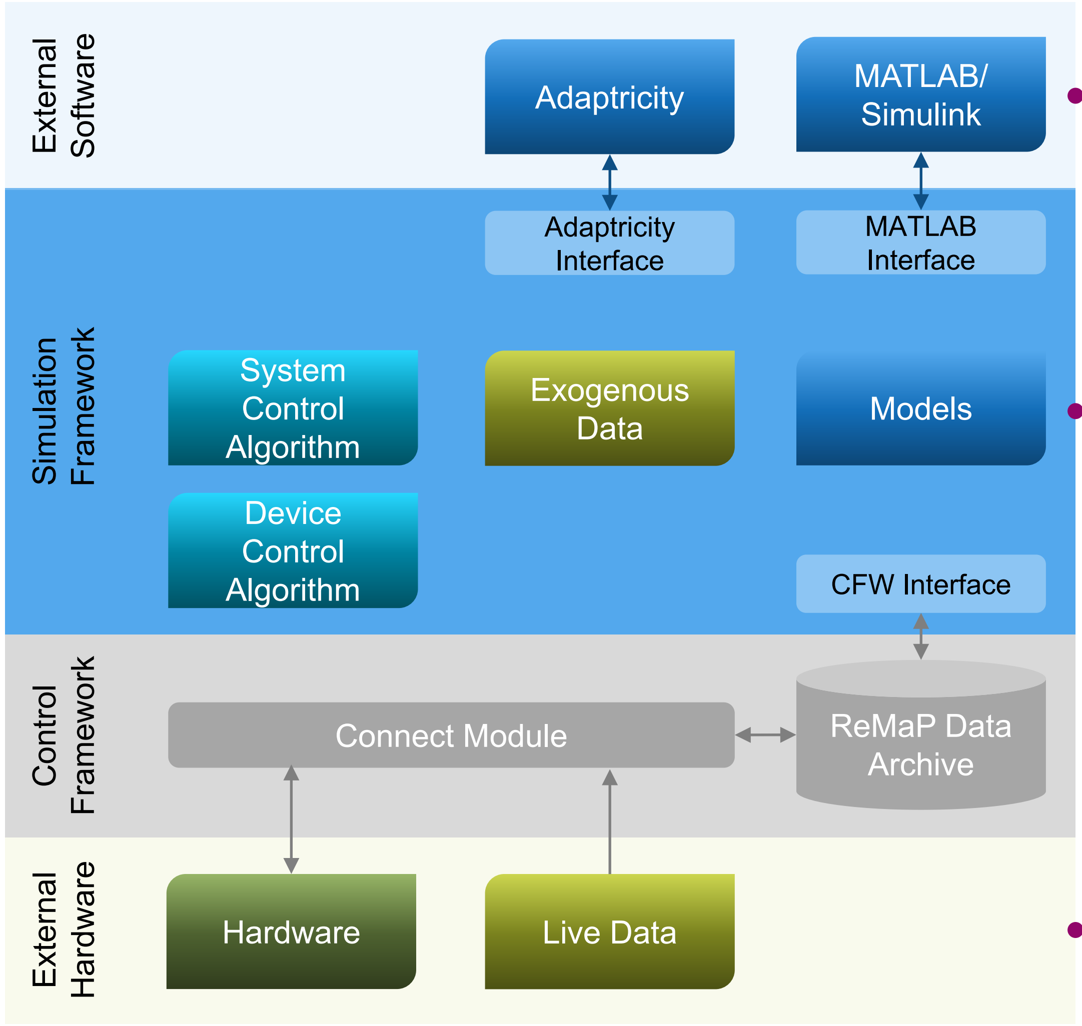

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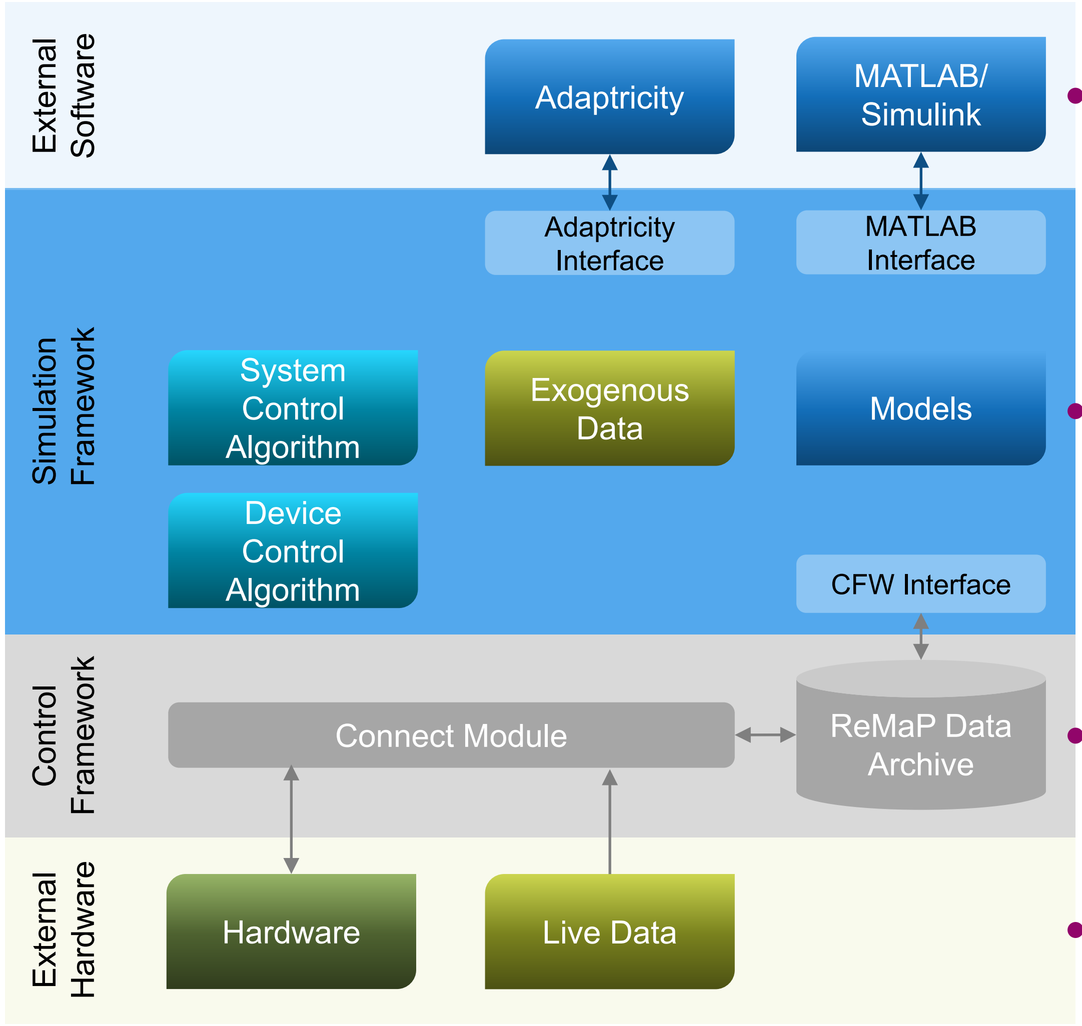
- ✓ Ability to connect to physical hardware components and to sources of live data (e.g. PV production), located at different places

Data | Controller | Model | Hardware

Features & Interconnections



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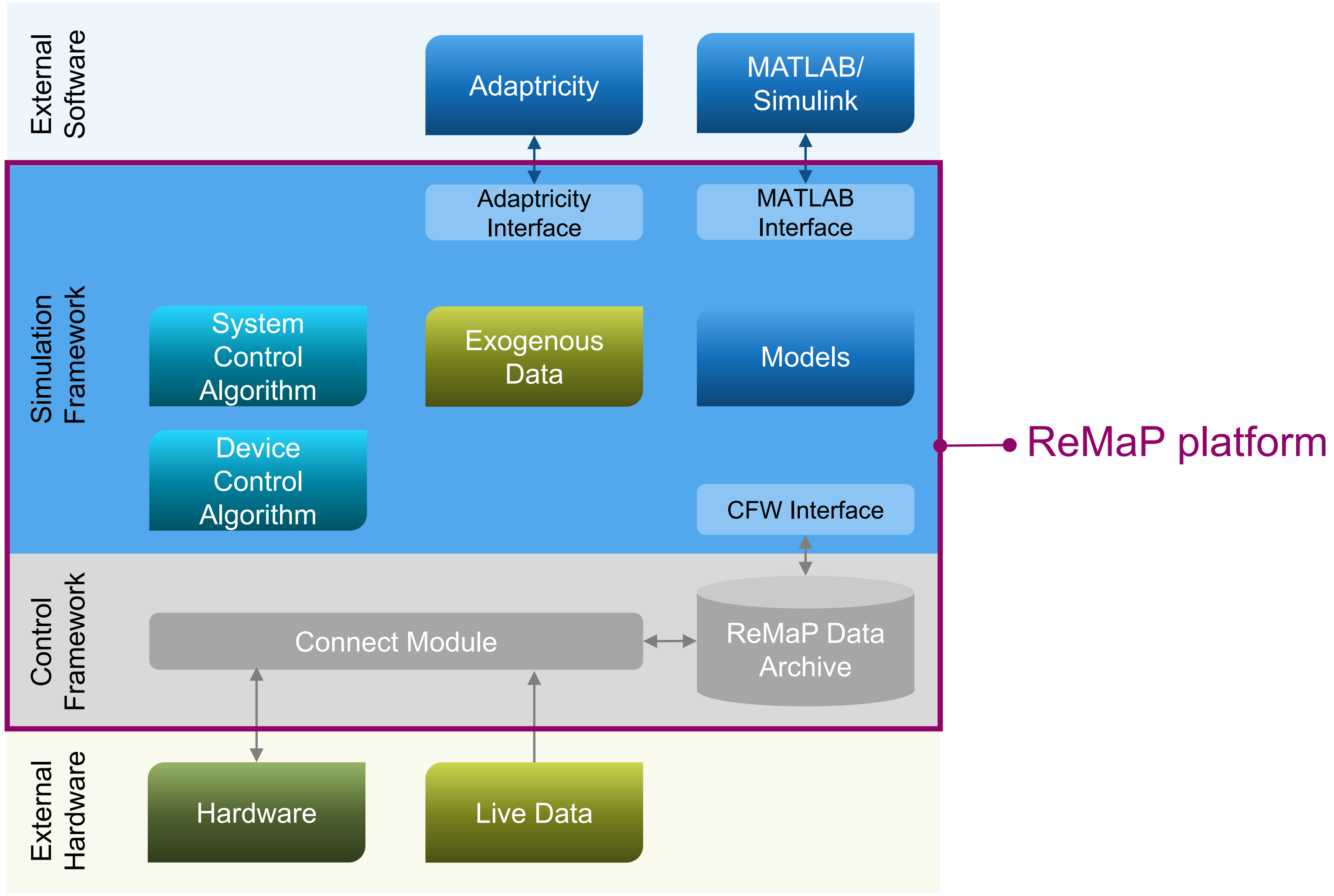
- ✓ Plug-and-play-ability for different independent models, algorithms and data to design systems per the user's needs
- ✓ No coding required by the user

- ✓ Interfaced to the ReMaP Control Framework (CFW), allowing
  1. access to the Data Archive and
  2. communication with the physical hardware

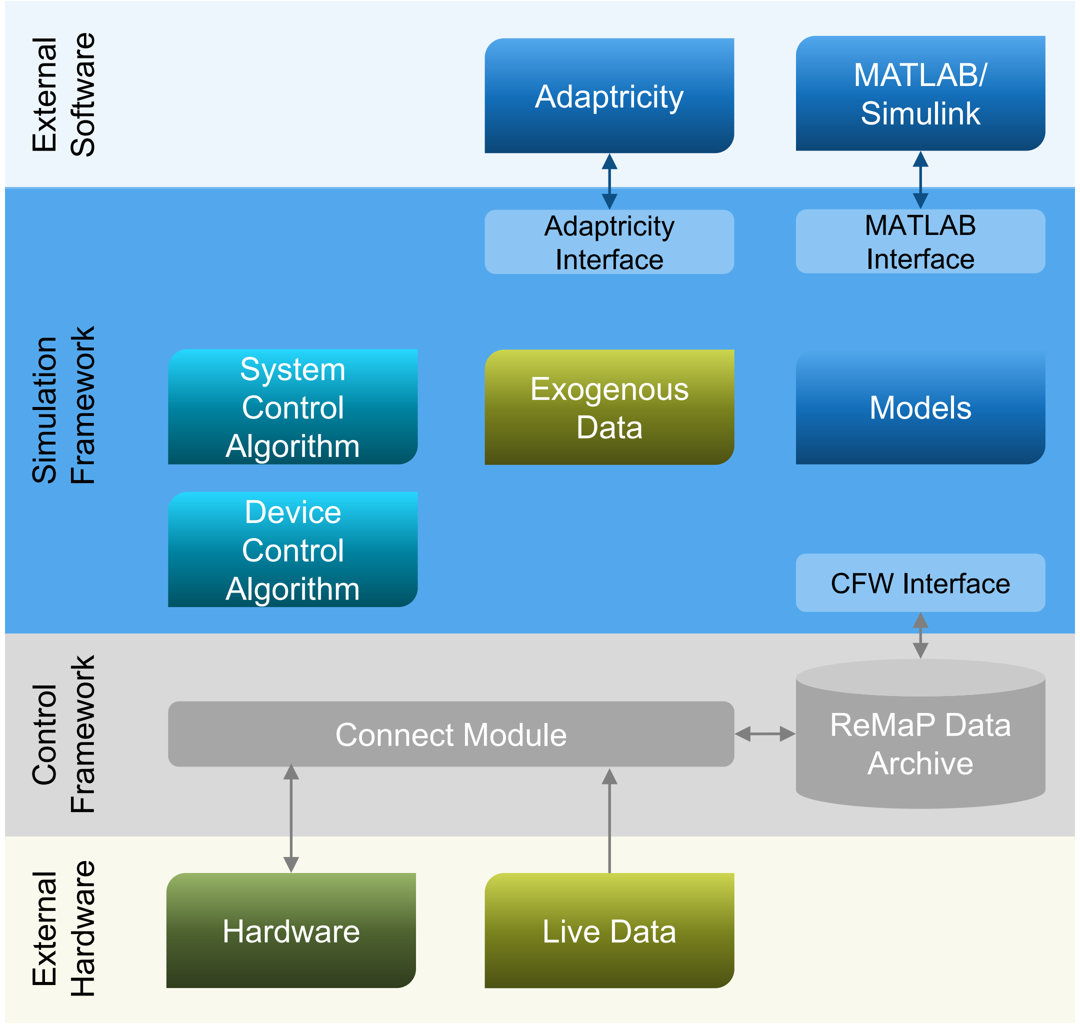
- ✓ Ability to connect to physical hardware components and to sources of live data (e.g. PV production), located at different places

Data Controller Model Hardware

Features & Interconnections



Model Library (continuously expanded)



Models integrated up to now

- Electricity Network
- Battery Storage
- Combined Heat and Power (CHP)
- Electrolyser
- Generation Timeseries (Wind, PV, etc.)
- Load Timeseries (Electric, Heat, Gas)
- Fuel Cell
- Heat Pump
- Hydrogen Storage
- Methanation Reactor
- Thermal Energy Storage (TES)

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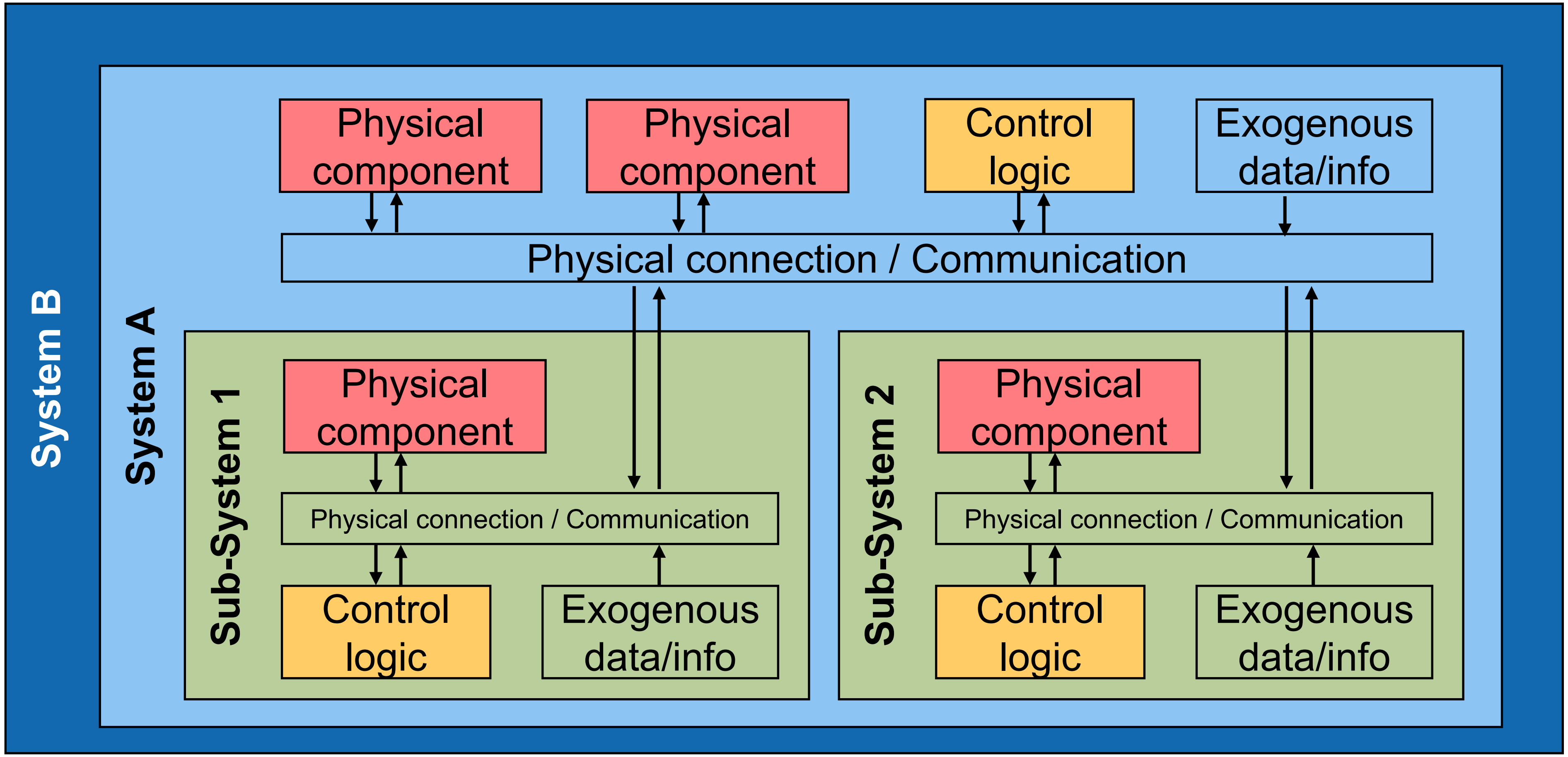
Basic architecture of SFW: A hierarchy of systems



Systems:

- pre-defined
- user-defined

Physical component:

- computeState()

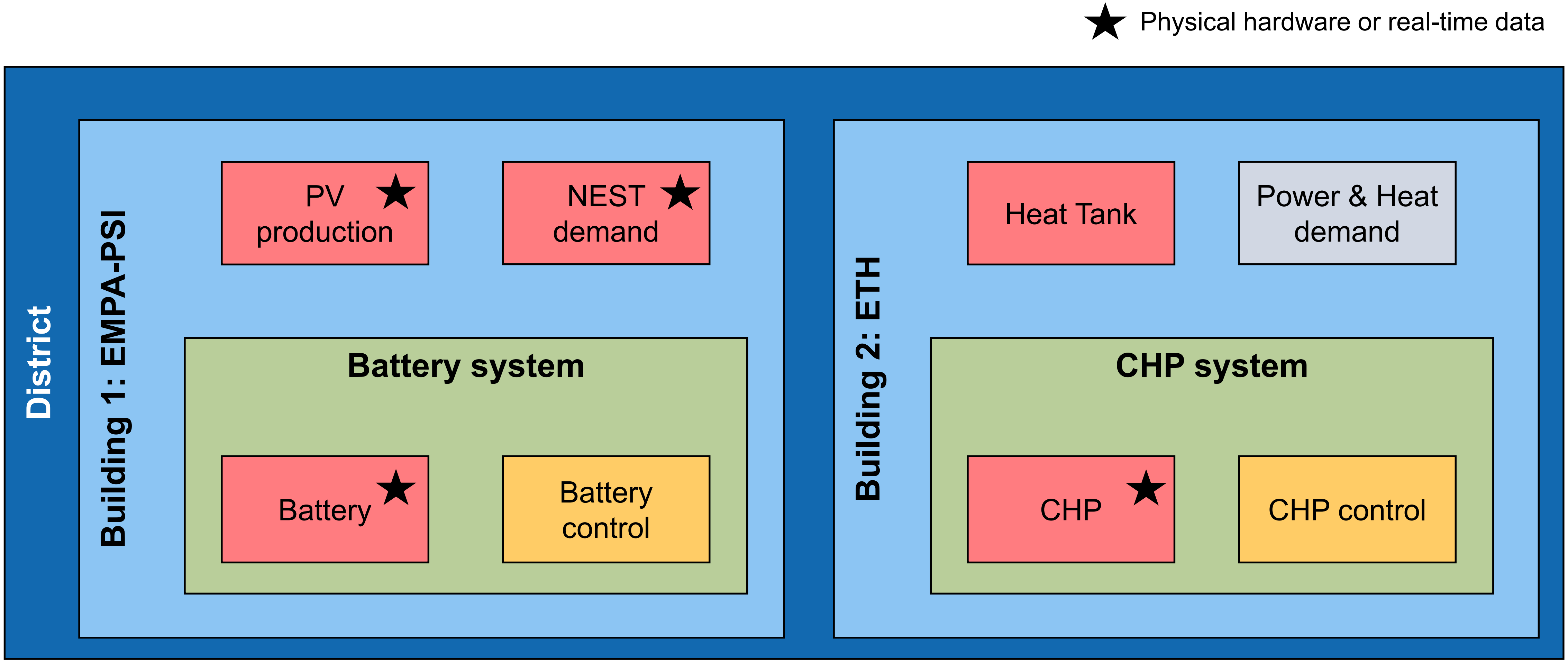
Control logic:

- computeAction()

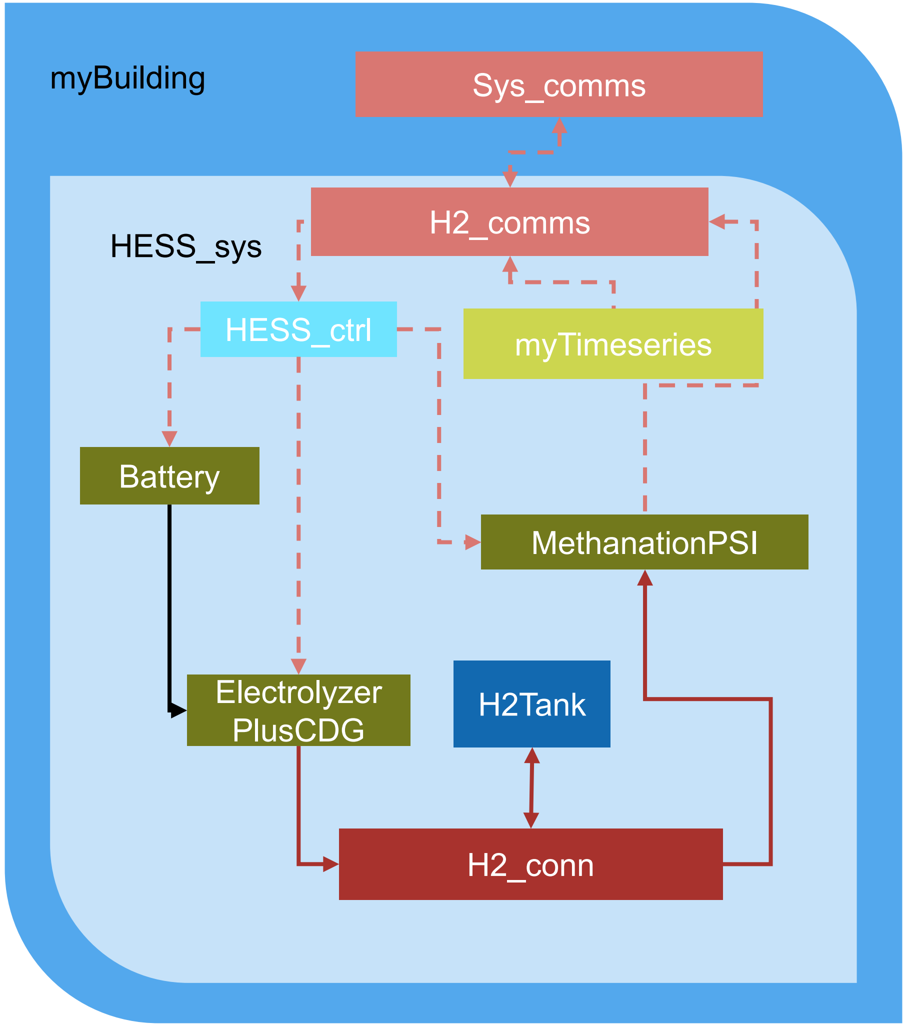
Exogenous data/info:

- timeseries/logic

Basic architecture of SFW: A hierarchy of systems



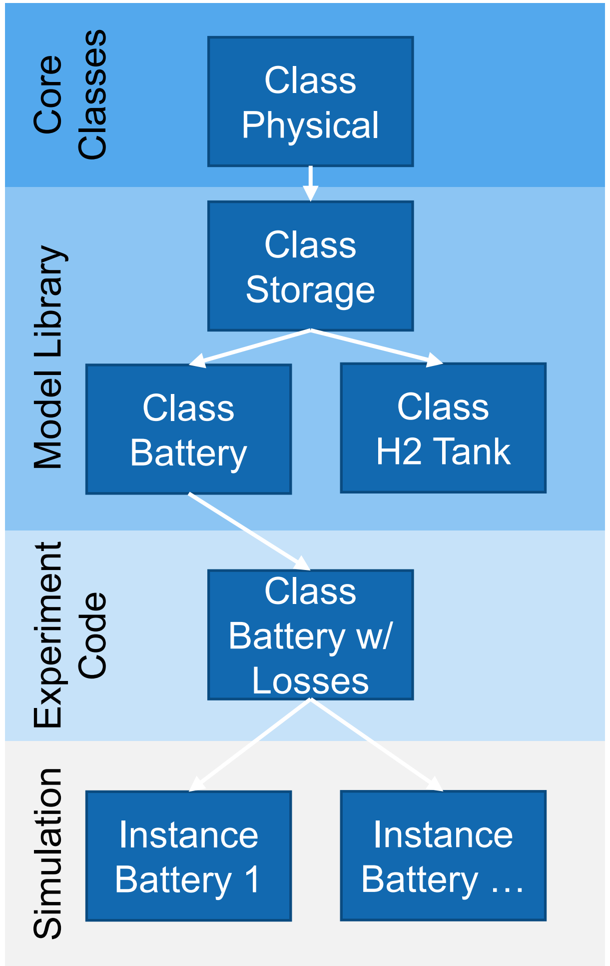
User Interface




```
myTimeseries = {'Name': ExogenousElectricity, 'Data': el_production}

# Hydrogen Energy Storage System setup
HESS_phys = {'Name': [Battery, ElectrolyserPlusCDG, MethanationPSI, H2Tank],
        'Param': [[{'P_max': float('inf'), 'P_min': -float('inf'), 'max_cap': Bat_cap, 'lookback’:
                    window_length, 'factor_battery': factor_bat},
                   {'P_init': P_bat_init, 'SoC_init': SoC_bat_init}, {'factor_time': factor_time}],
                  [{'eff_HHV': eta_ely, 'eta_cdg': eta_cdg, 'rated_input': float('inf')},
                   {'P_init': P_ely_init}, {'P_el_key': 'P_Ely_setpoint', 'leakage_offset': leakage_offset}],
                  [{'P_H2_rated': MR_rating, 'factor_methanation': factor_methanation, 'eff': MR_eff},
                   {'H2_init': MR_H2_init}, {}],
                  [{'capacity': float('inf')}, {'SoC_init': H2_SoC_init},
              {'P_net_key': 'H2_conn_up_00', 'sim_H2_tank': sim_H2_tank, 'factor_time': factor_time}]]}
H2_control = {'Name': HESS_ctrl,
        'Param': [{'factor_time': factor_time, 'factor_ely': factor_ely, 'factor_bat': factor_bat, 'llim': llim,
              'ulim': ulim, 'cap_H2': H2_tank_cap, 'cap_bat': Bat_cap, 'eta_ely': eta_ely,
              'SoC_bat_lim_low': SoC_bat_lim_low, 'eta_elysim': eta_elysim, 'eta_cdg': eta_cdg,
              'P_Ely_max': P_ely_max, 'leakage_offset': leakage_offset, 'P_Bat_max': P_bat_max,
              'P_Bat_min': P_bat_min, 'SoC_min': Min_SoC, 'SoC_max': Max_SoC},
             {'u_Ely_init': ctrlEly}, {}]}
H2_conn = {'Name': [H2Connector], 'Param': [[{'outputConnections': 1}, {'name': 'H2_conn'}, {}]]}
H2_comms = {'Name': [HESS_comms], 'Param': [{}]}

# Overall system setup
sysObjs = {'Name': [HESS_sys], 'Param': [[H2_control, myTimeseries, HESS_phys, H2_conn, H2_comms]]}
sys_comms = {'Name': [SysComms], 'Param': [{}]}

myBuilding = Building(None, None, None, sysObjs, None, sys_comms)
```

- Timeseries Data
- Execution Order
- Battery Param.
- Electrolyser Param.
- Methane Param.
- H2 Tank Param.
- Control Param.
- Connector
- HESS Comms
- System Layout
- Building Comms
- Overall Model

Object-oriented approach




```
class Storage(coreClasses.Physical):
"""Base class for all storage systems: Storage class inherits from Component class
    and implements basic storage with physical limits"""
    def __init__(self, model_param, init_param, sim_param):
        super().__init__(model_param, init_param, sim_param)
```

Storage parameters

```
        self.P_net = init_param.get('P_init', 0) # Net power flow into storage in W
        self.SoC = init_param.get('SoC_init', 0) # State of charge in Wh
        self.max_cap = model_param.get('capacity', float('inf')) # Max capacity in Wh
        self.P_net_key = sim_param.get('P_net_key', 'P_STRG_in') # Key name for P_net input
```

Base method calling storage model code

```
    def computeState(self, com_bus, connector):
        self.P_net = connector[self.storage_type].bus['connected_up'][self.P_net_key].power
        self.run_storage_model()
        return [self.SoC, self.P_net]
```

Actual model formulation

```
    def run_storage_model(self):
        self.SoC = self.SoC + self.P_net * TimeKeeping.dt / 3600
        self.SoC = self.check_physical_lims(self.SoC, 0, self.max_cap, action='lim&warn’)
```

```
class BatteryLosses(Battery):
```

Extend model parameters

```
    def __init__(self, model_param, init_param, sim_param):
        super().__init__(model_param, init_param, sim_param)
        self.charge_loss = model_param.get('charge_loss', 0.01) # Charging loss in percent
        self.discharge_loss = model_param.get('discharge_loss', 0.01) # Discharging loss in %
```

Add experiment specific modelling detail

```
    def account_for_losses(self):
        if self.P_net > 0:
            self.P_net *= (1 - self.charge_loss)
        elif self.P_net < 0:
            self.P_net *= 1 / (1 - self.discharge_loss)
```

Update storage model without rewriting

```
    def run_storage_model(self): # Include losses into predefined storage model
        self.account_for_losses()
        super().run_storage_model()
```

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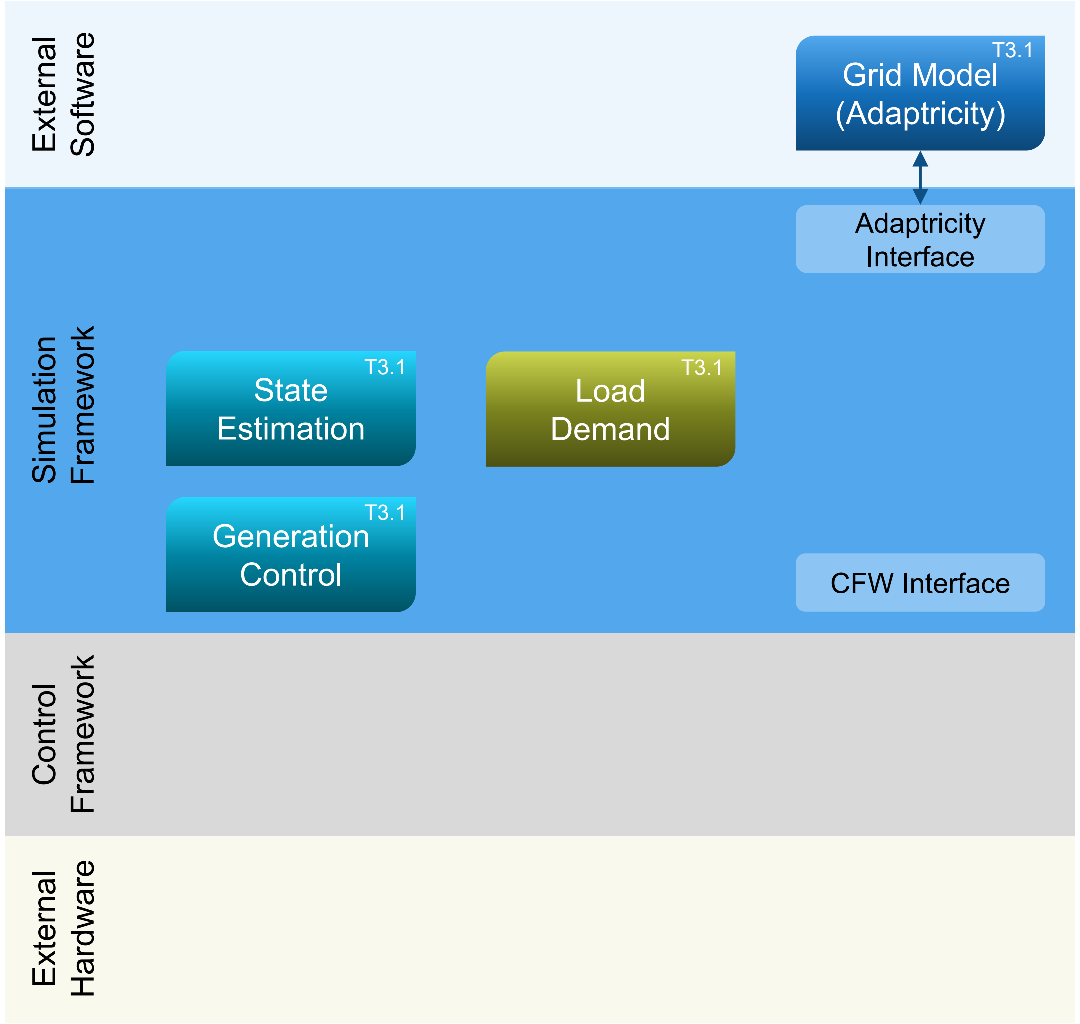
ReMaP Task 3.1



Why

- Testing the online feedback optimization approach for real-time grid operation on a realistic simulation framework

What

- Simulation only (future connection to grid @Empa)
- Utilizing sparse real-time grid measurements to dynamically estimate the grid state, and choose the controllable generation set-points minimizing the operation cost while satisfying the grid constraints
- Grid modelled on Adaptiricty, power flow calculation via Adaptricity API

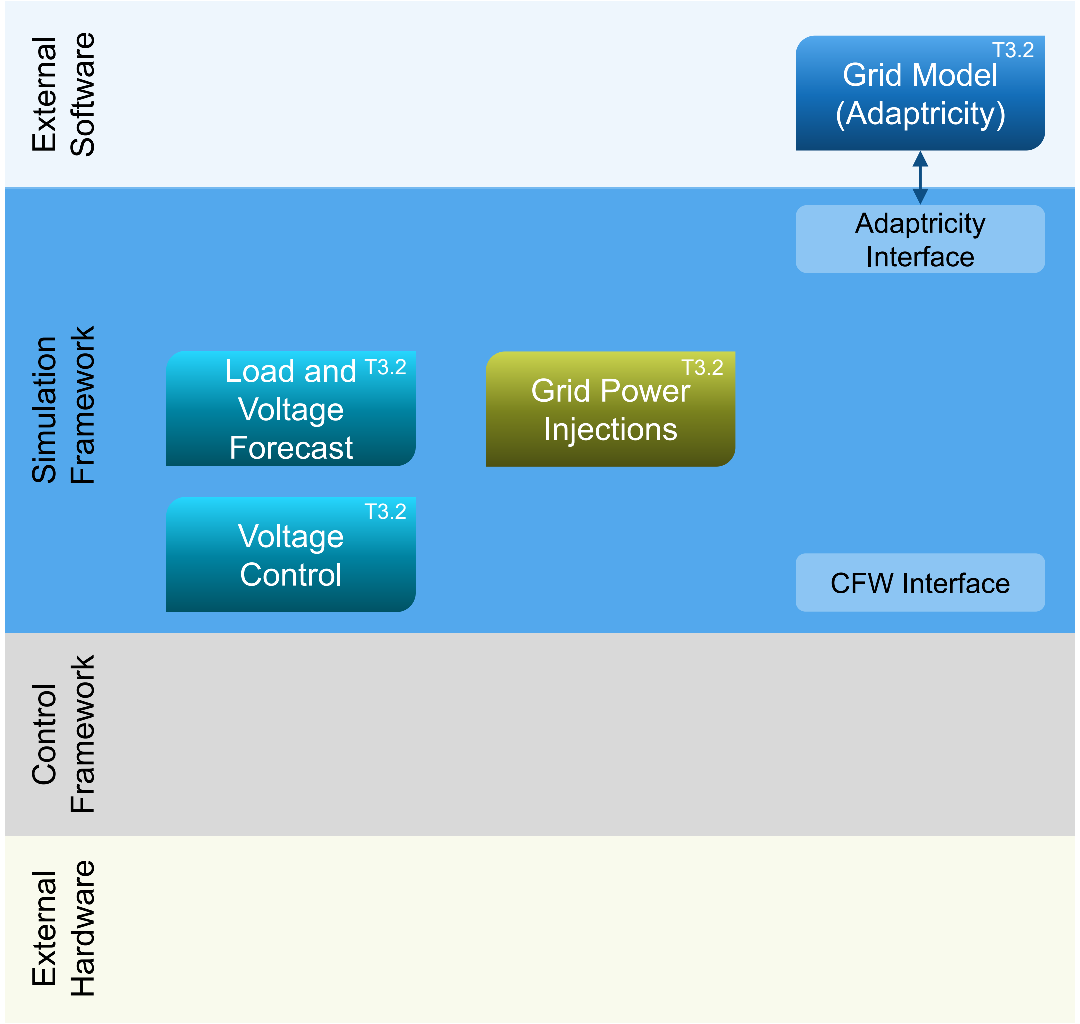
Who

- ETH Zürich, Automatic Control Laboratory

When

- August 2021 – ongoing

ReMaP Task 3.2



Why

– Developing a preventive control scheme based on thermostatically controlled loads and probabilistic predictions

What

– Simulation only
– Live data integration to follow
– Probabilistic load and voltage predictions for demand response purposes
– Grid modelled on Adaptiricty, timeseries power flow calculation via Adaptricity API

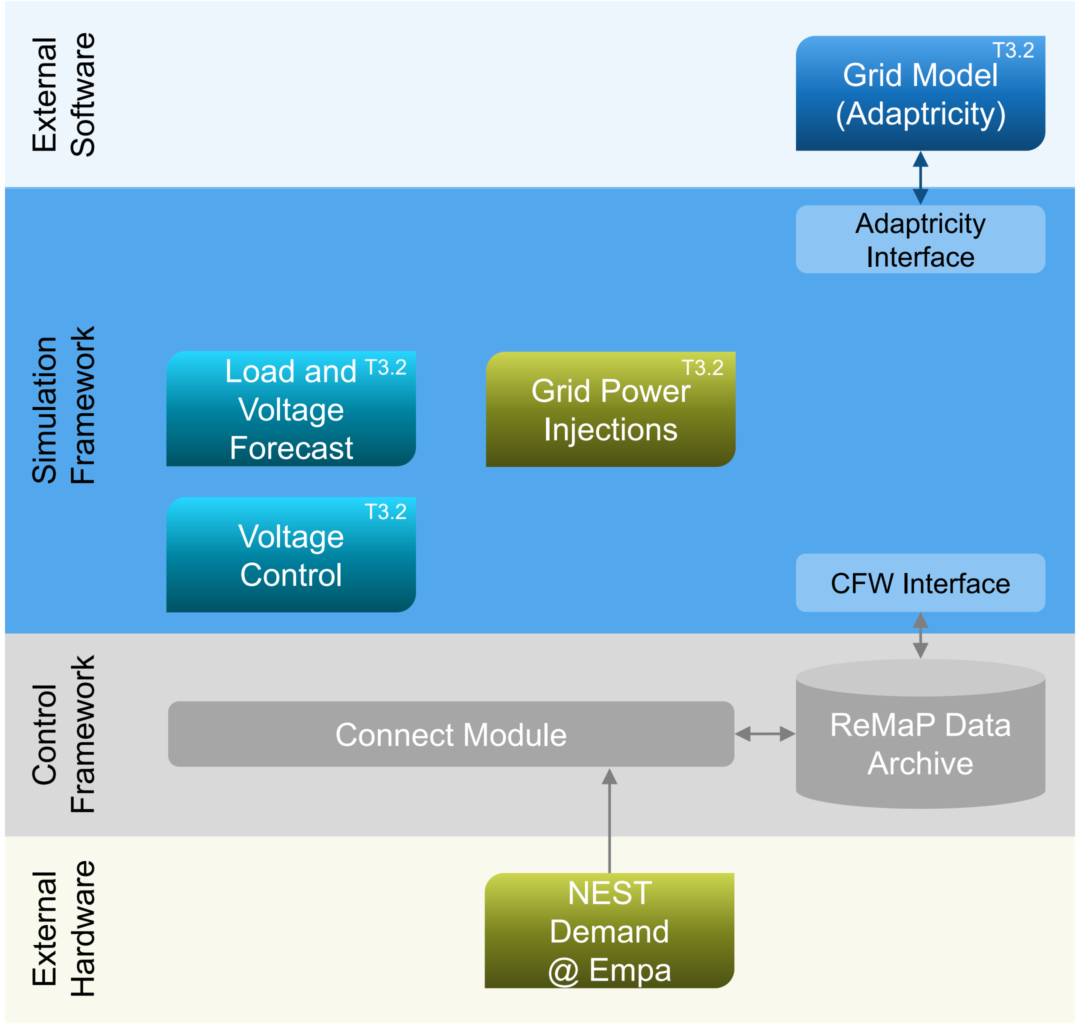
Who

– ETH Zürich, Power Systems Laboratory PSL

When

– August 2021 – ongoing

ReMaP Task 3.2 (Outlook)



Why

- Developing a preventive control scheme based on thermostatically controlled loads and probabilistic predictions

What

- Integrated demand data from NEST @Empa
- Probabilistic load and voltage predictions for demand response purposes
- Grid modelled on Adaptiricty, timeseries power flow calculation via Adaptricity API

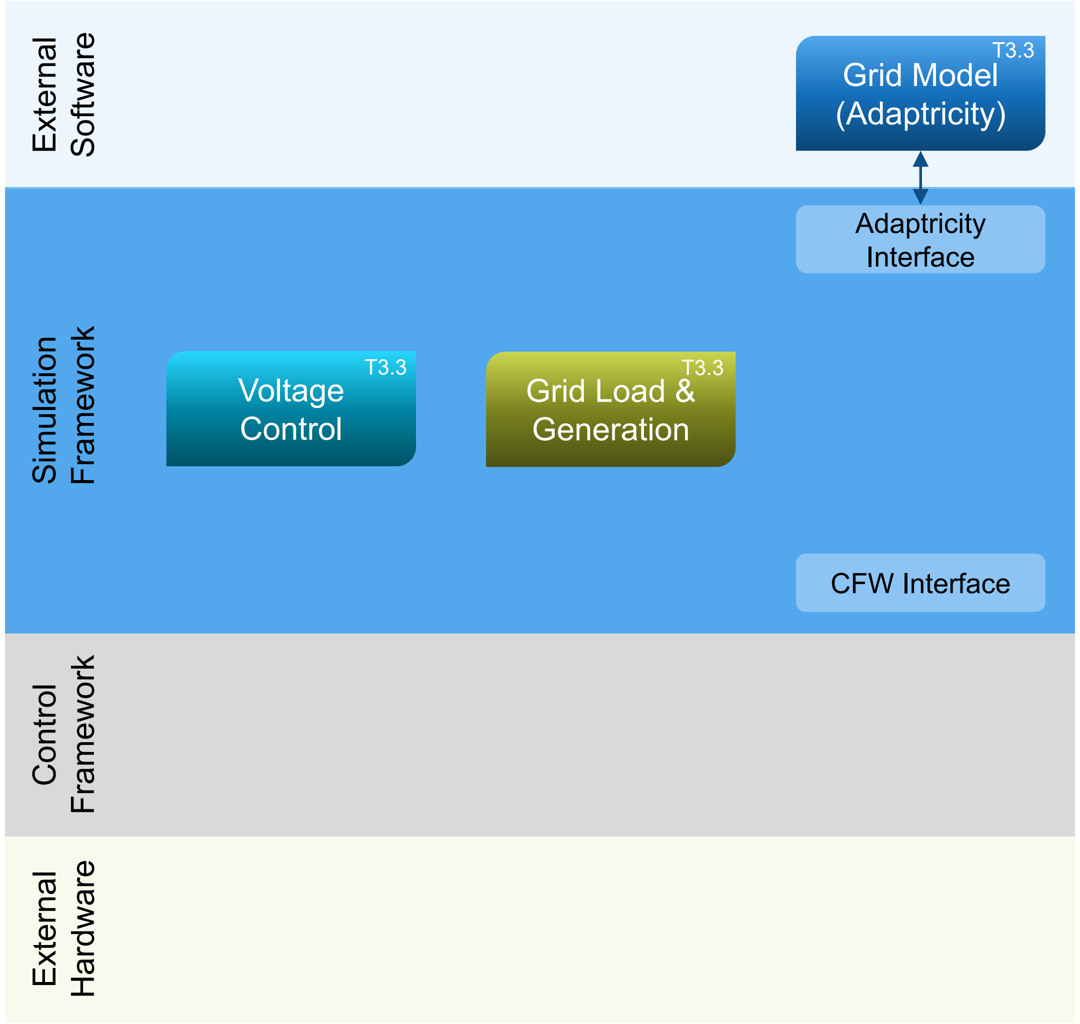
Who

- ETH Zürich, Power Systems Laboratory PSL

When

- August 2021 – ongoing

ReMaP Task 3.3



Why

- Quantify the impacts and benefits of active distribution networks on their hosting networks, considering the electrification of heating and mobility

What

- Simulation only
- Active distribution network control
- Controller changes the power output of controllable distributed energy resources whenever voltage or flow issues arise
- Grid modelled on Adaptiricty, power flow calculation via Adaptricity API

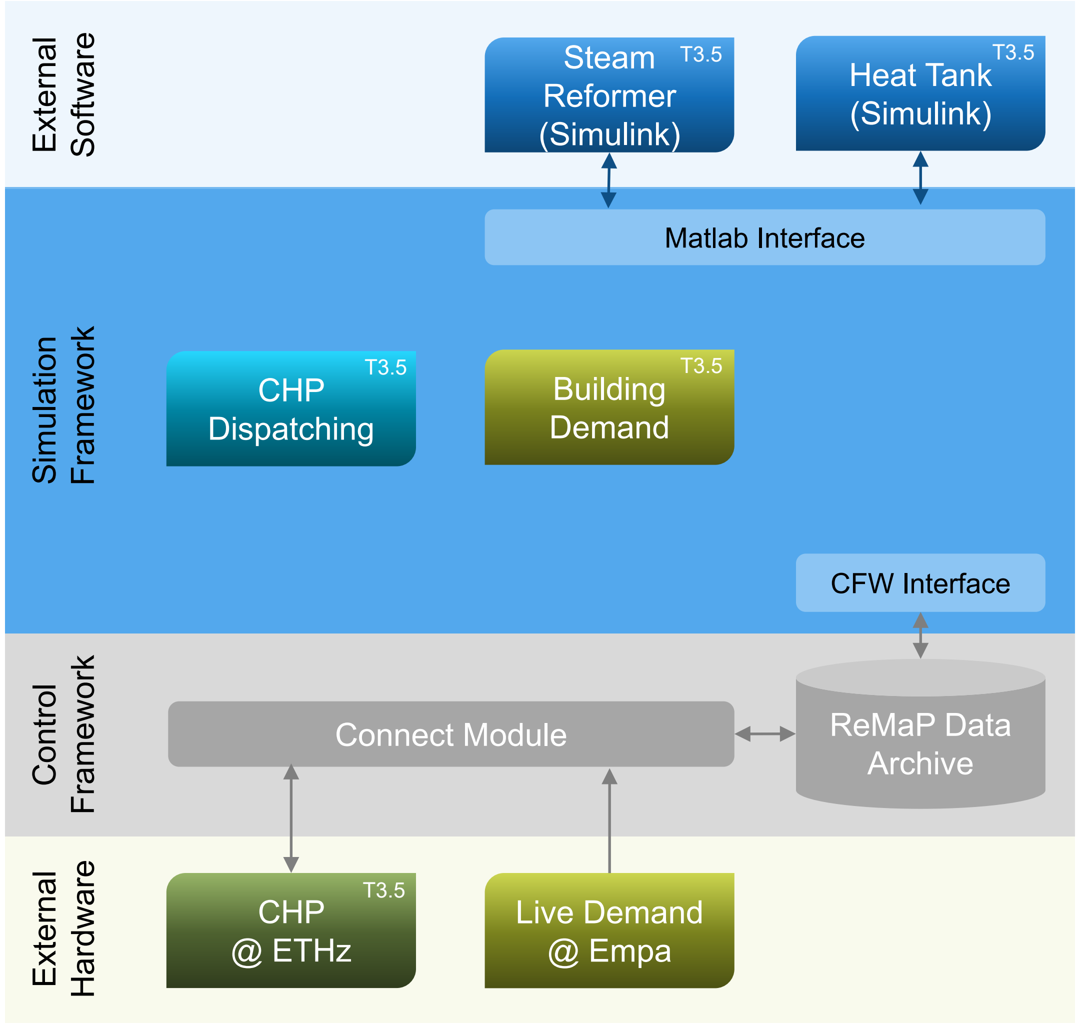
Who

- ETH Zürich, Reliability and Risk Engineering RRE

When

- July 2021

ReMaP Task 3.5



Why

- Evaluating system performance benefits from improved dispatching control and added components before modifying hardware

What

- Hardware-in-the-loop: CHP prototype at ETHz
- CHP plant, providing heat input for thermal storage and steam reformer models in Simulink
- HW dispatching through control algorithm in SFW based on model feedback and exogenous demand data

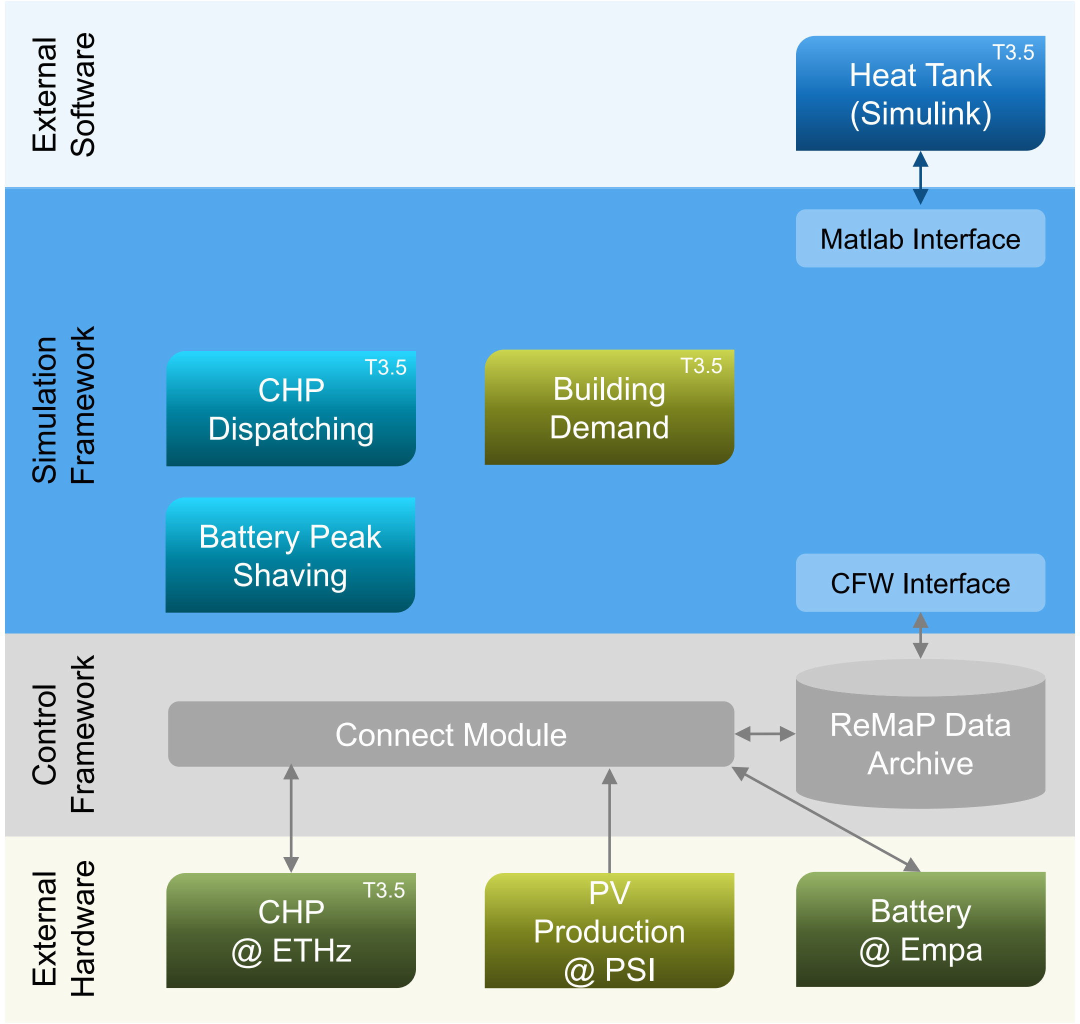
Who

- ETH Zürich, Laboratory of Aerothermochemistry and Combustion Systems LAV

When

- August 2020 – January 2021

ReMaP Task 3.8 SFW Showcase



Why

– Showcasing the functionality of the Simulation Framework and Control Framework

What

– Hardware-in-the-loop
– CHP plant, providing heat input for thermal storage to supply building heat demand
– Battery balances PV and CHP production and building electricity demand

Who

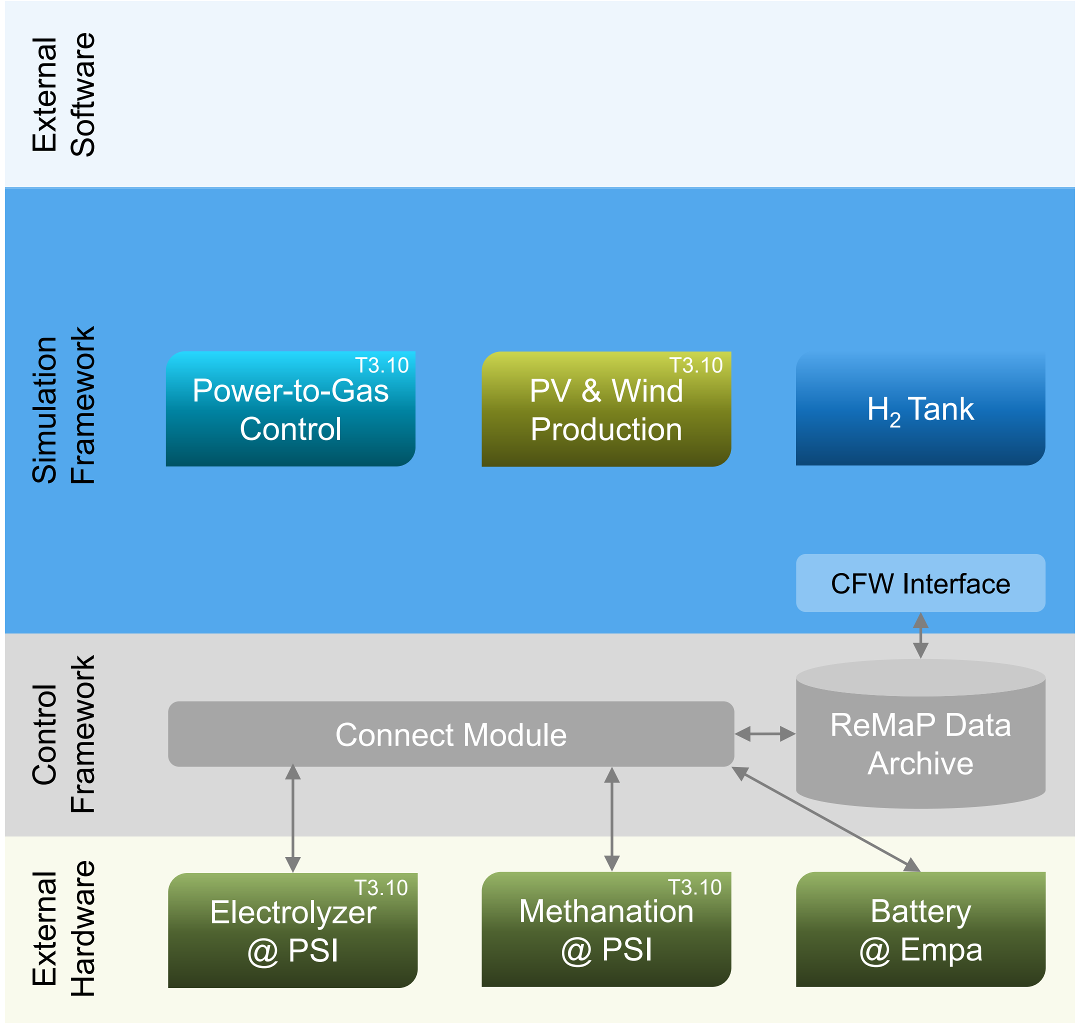
– ETH Zürich, Research Center for Energy Networks FEN
– Empa, Urban Energy Systems Laboratory

When

– November 2020 – December 2020

Data Controller Model Hardware

ReMaP Task 3.10, Case 1



Why

- H2 Mobility without using winter-electricity (seasonal storage)

What

- Hardware-in-the-loop: electrolyzer at PSI (ESI platform), battery at Empa, methanation reactor at remote location
- H_2 tank model virtually tracking hydrogen balance
- HW dispatching and control through control algorithm in SFW based on model feedback and exogenous demand data

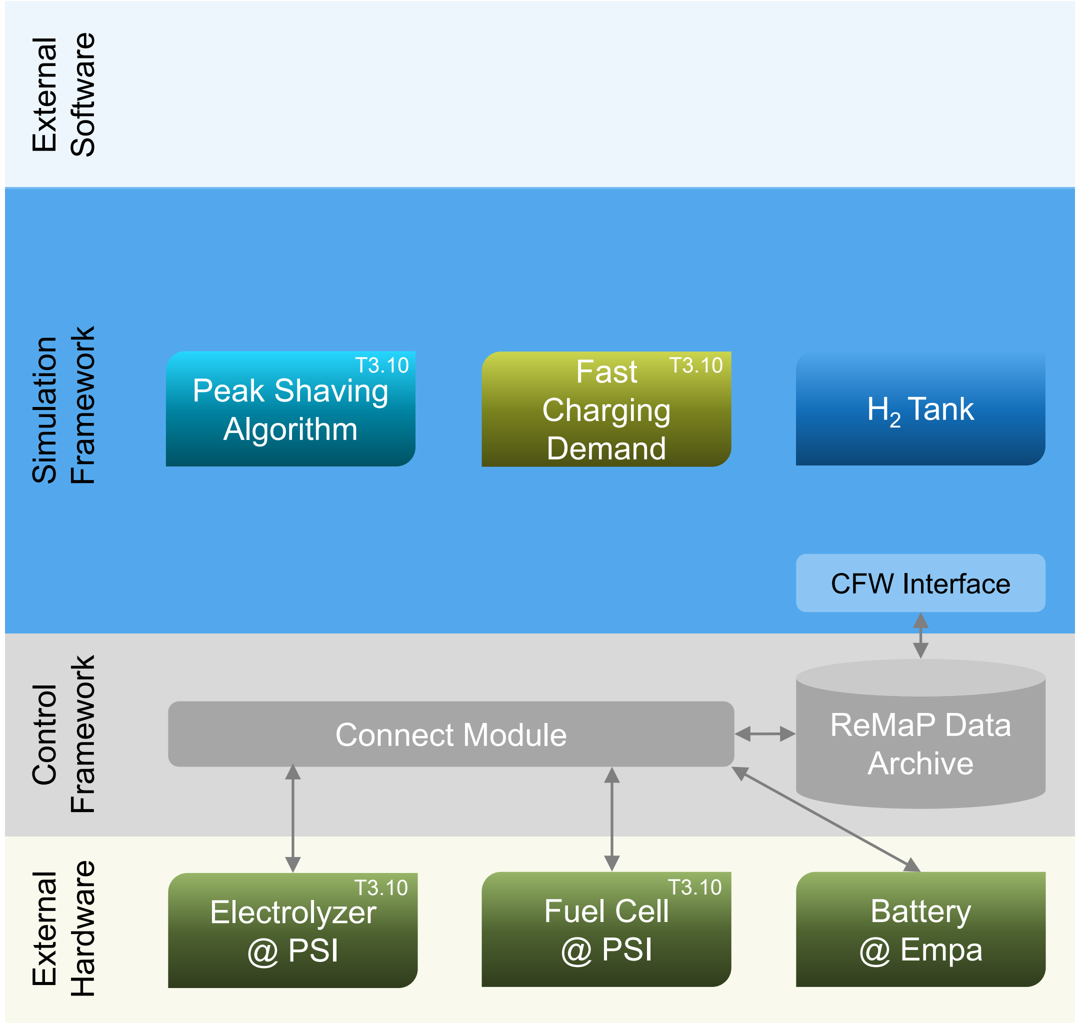
Who

- PSI, Bioenergy and Catalysis Laboratory LBK
- PSI, Electrochemistry Laboratory LEC

When

- June 2021 – July 2021

ReMaP Task 3.10, Case 2



Why

- Investigating peak shaving algorithms for electric vehicle fast charging stations

What

- Fast charging station peak shaving with power-to-gas-to-power
- Hardware-in-the-loop: electrolyzer and fuel cell at PSI (ESI platform), battery at Empa
- H_2 tank model virtually tracking hydrogen balance
- HW dispatching and control through control algorithm in SFW based on model feedback and exogenous demand data

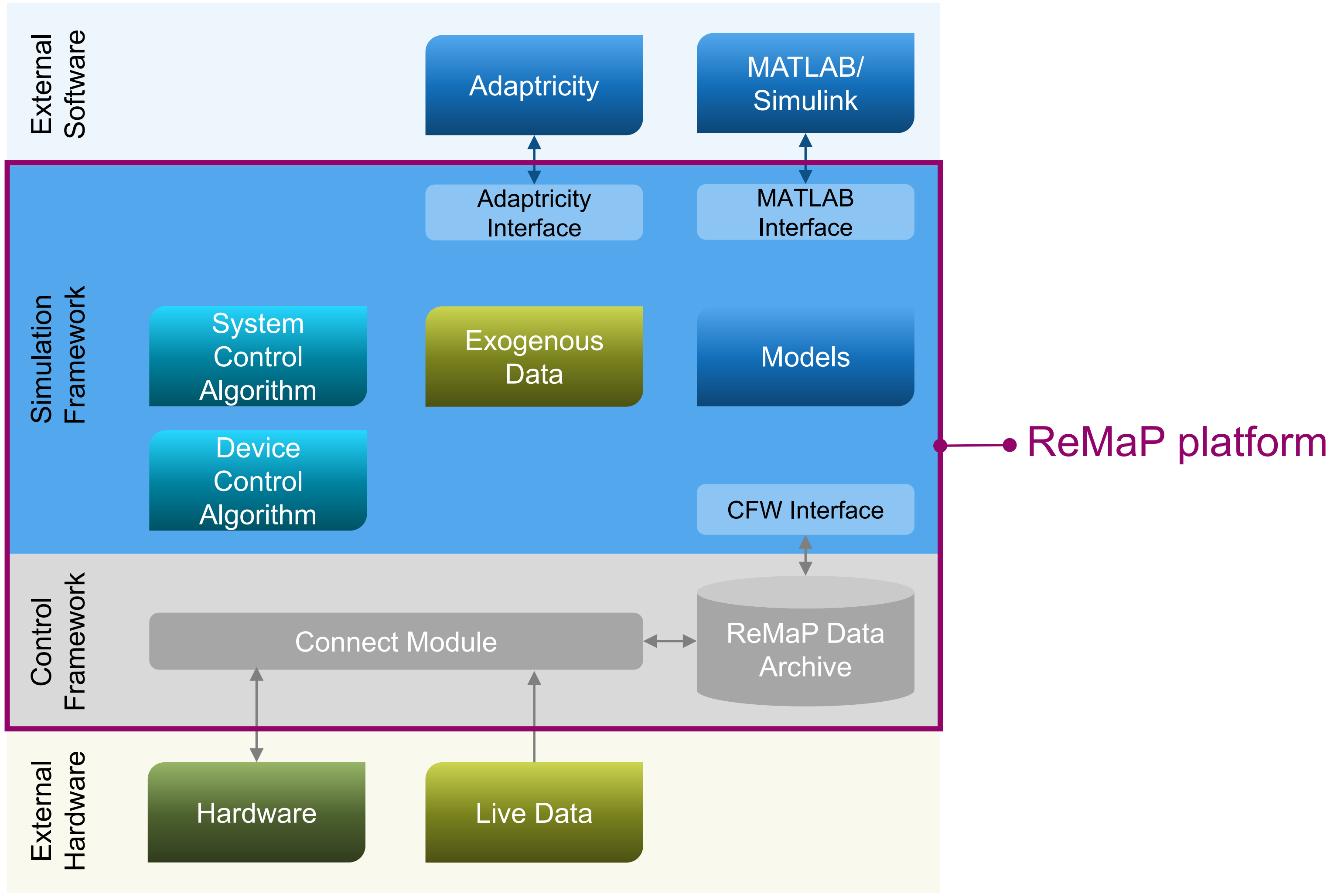
Who

- PSI, Electrochemistry Laboratory LEC

When

- June 2021 – September 2021

Simulation Framework as part of the ReMaP platform



Data Controller Model Hardware

ETH zürich

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