



BIOND 4.0 – Offline demonstrator Architecture / Platform for Digital Twin

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Agenda

- Architecture
- Implemented OPC UA Servers and OPC UA Clients
 - Current status: tested with UaExpert (screenshots)
- Next actions:
 - FMU model needed or some other to make predictions (Aalto researcher tests on-going)
 - OPC UA Client to connect FMU Server (or other model) and Bioreactor Digital Twin server
- Latest version changes:
 - Added error checking/handling/messages/return codes
 - Certificate:

| | | | | | | | | | |
|--------|-----------------------------------|-------------|-----------------|-----------|-----|---------------------|-----------------------------------|---------|-----------|
| ✓ T... | urn:OPCUA-BIOREACTOR:DIGITAL-TWIN | 23/05/20... | 23/05/2026 8:34 | BIOND 4.0 | RTD | TAMPE... PIRK... FI | urn:OPCUA-BIOREACTOR:DIGITAL-TWIN | GX73364 | 127.0.0.1 |
|--------|-----------------------------------|-------------|-----------------|-----------|-----|---------------------|-----------------------------------|---------|-----------|
 - Better functionality, no hard coded variables: add/delete vendor(s) & variables, save / load address space

Architecture – modular and scalable

Offline / online demonstrator

Forecast client
can read
historical values &
write predictions

OPC UA
Client(s)
Forecast

OPC UA
Client(s)
Charts

Charts can be used to visualize
wanted variables/predictions

OPC UA
Server(s)
Digital Twin
for Bioreactor

Digital Twin contains address space for all
variables for measurements and predictions,
can be used for any process

FMU model can be imported,
and simulation can be run

OPC UA
Server(s)
FMI

OPC UA
Client(s)
DT runner

DT runner client will read measurements
from the Digital Twin server and call model
simulation and write predictions back to
Digital Twin server

OPC UA
Client(s)
Real-Time

OPC UA Client can read actual
measurement from the vendor
OPC UA Server like PixAct and
write them to Digital Twin OPC
UA Server

OPC UA
Server(s)
PixAct etc.

OPC UA Server
for Bioreactor
measurements

OPC UA Server FMI and Digital Twin client

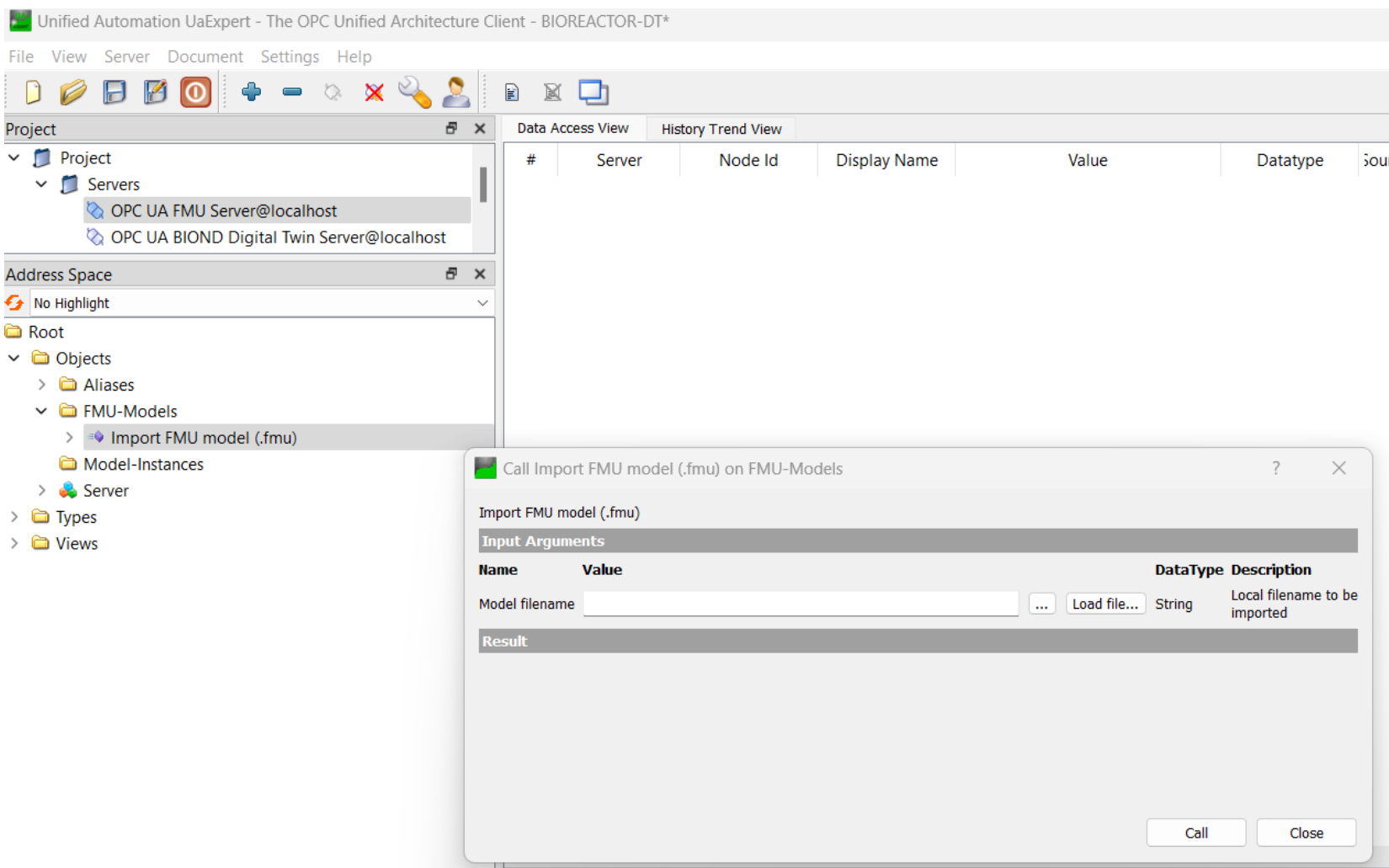
- User can import FMU file, instantiate model and run simulation
 - Digital Twin client can call methods: import, instantiate and run.
 - It will synchronize needed variables from the Bioreactor DT server for simulation inputs and read model outputs and write them back to the Bioreactor DT server as predictions
- As model can be run and fine tuned with the actual measured values so that predictions will match this will need some additional parameters inside FMU model for this purpose

OPC UA Server for Bioreactor as Digital Twin

- User can import excel file that will create all variables into the address space
 - Additional own namespace variables are created at the same time for predictions
- Replay will write values from the Pandas data frame into the server
 - Uses current time and writes all values into the future historical values (time delta can be modified to run faster)
 - Start time can be given as parameter for the replay
 - Interval can be given as parameter for the replay (faster or slower than recorded)
 - This will enable that simulation can read offline values as “real-time” and execute model and server will predict values
 - Model can also use historical values and re-fit model and new prediction with new model (validate and check error before using new prediction values)

Screenshots from the FMU OPC UA Server

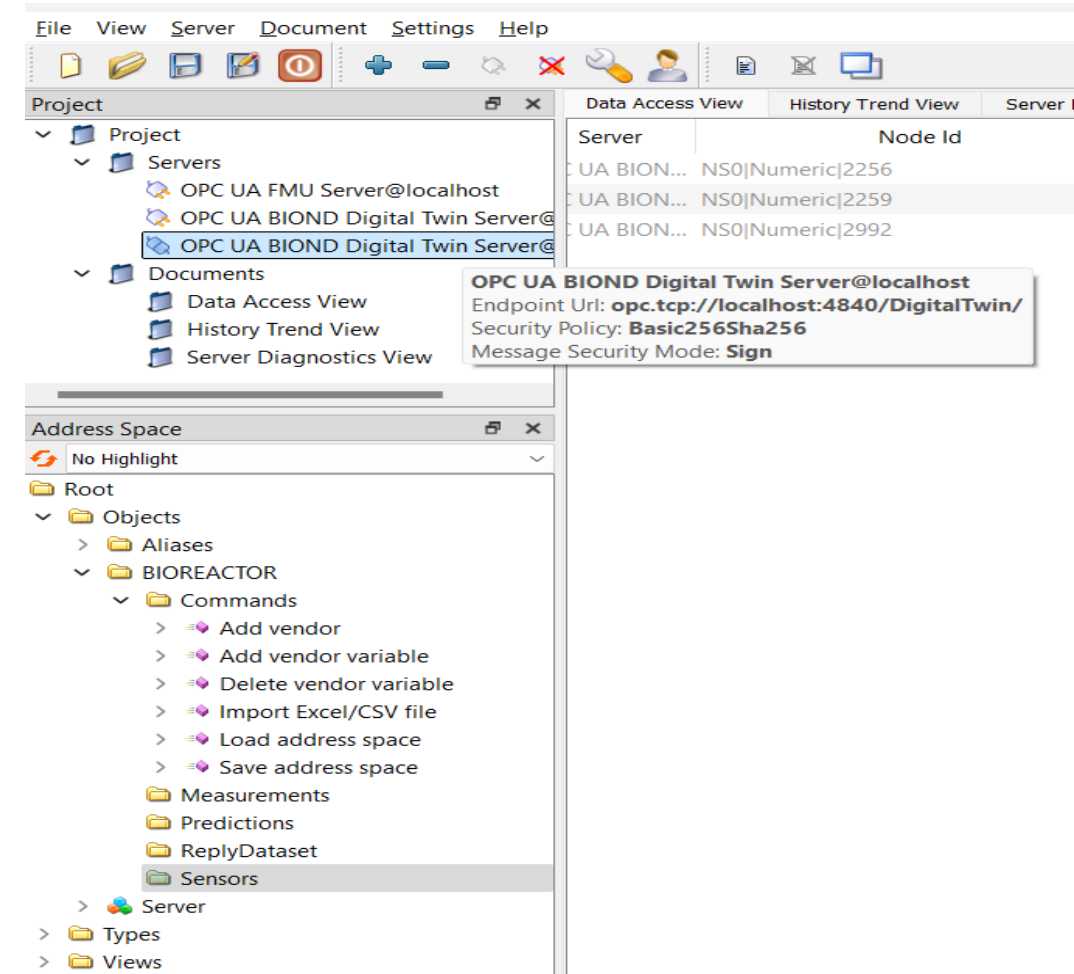
Bioreactor FMU model can be imported and then instantiate, and simulation could be run



Screenshot from the Bioreactor Digital Twin OPC UA Server

BIOREACTOR Server started – Import recorded data (Excel file format)

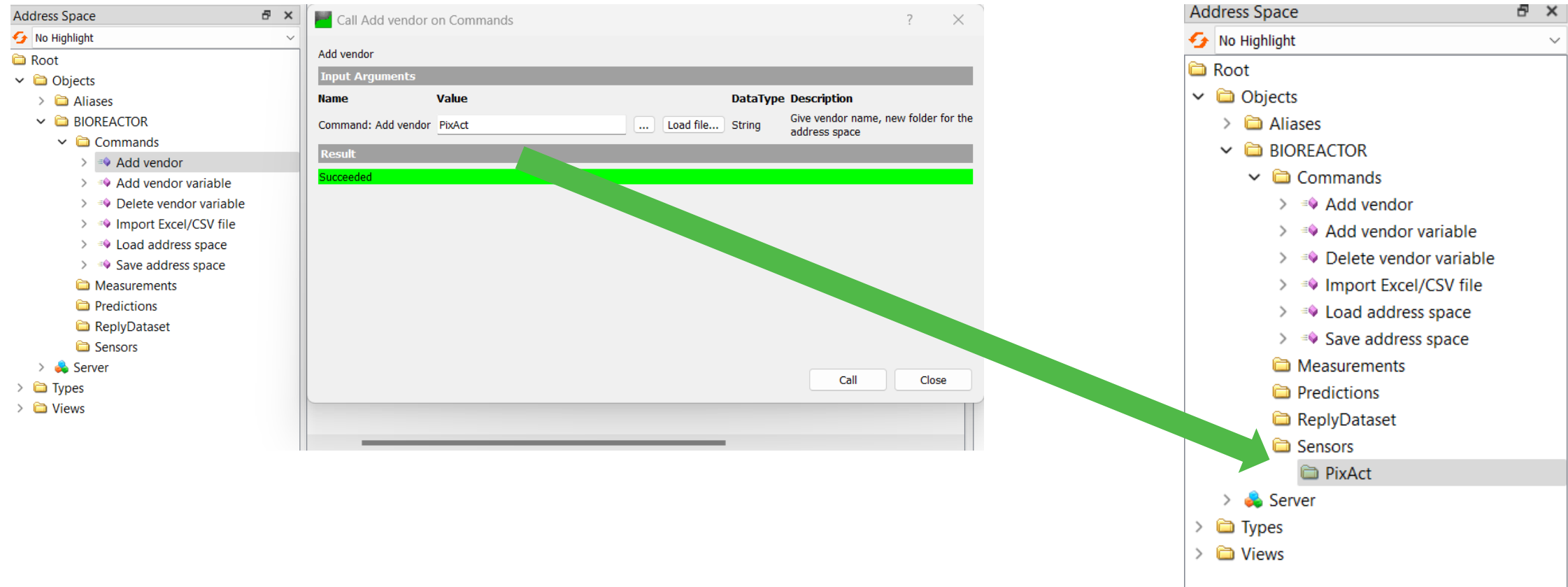
- Server supports now username & password (Sign)
- Certificates are under certificates folder (Encrypt)
- All methods are under Commands folder
- Add vendor will create folder under Sensors
- Add vendor variable will add variable under just created Sensors/*VendorName* folder
- Delete vendor variable can be used to remove vendor variable
- Import Excel/CSV file will read dataset from the file
- Load address space will read XML format file
- Save address space will write XML format file



Screenshot from the Bioreactor Digital Twin OPC UA Server

BIOREACTOR Server: Add vendor

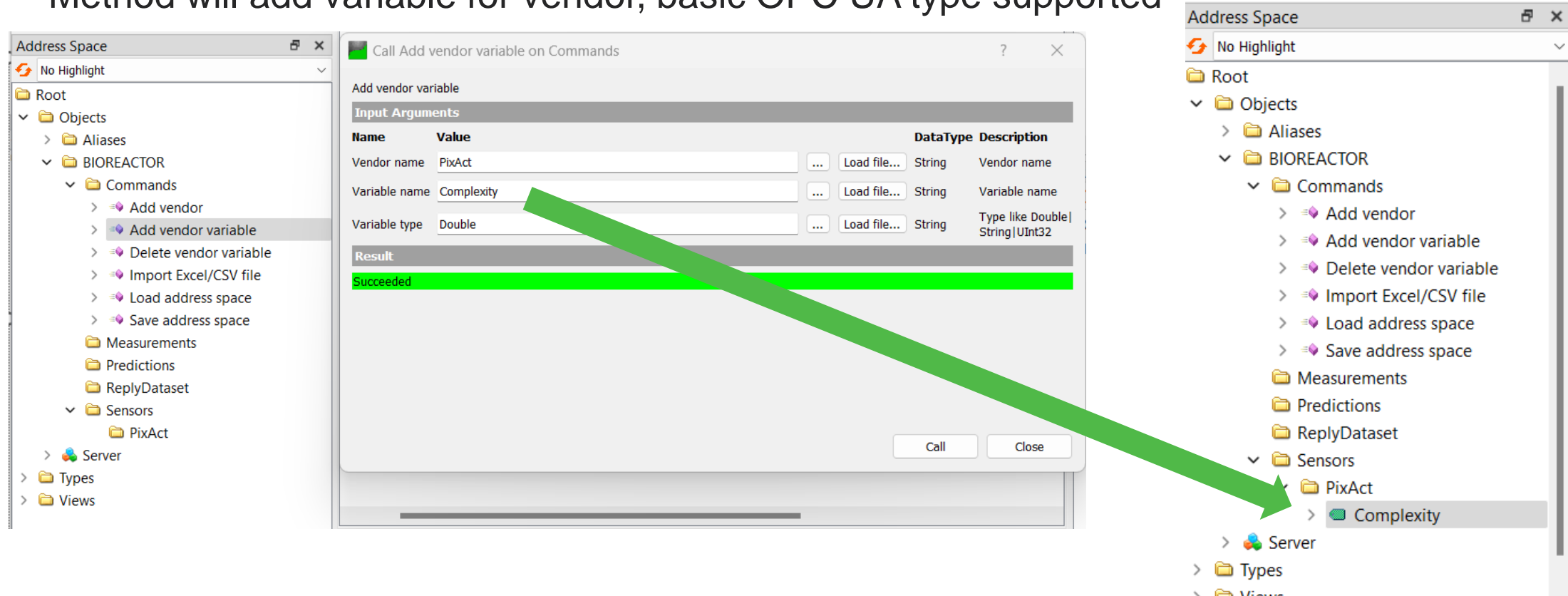
- Method will add folder under Sensors folder (easier to see vendor specific measurements)



Screenshot from the Bioreactor Digital Twin OPC UA Server

BIOREACTOR Server: Add vendor variable

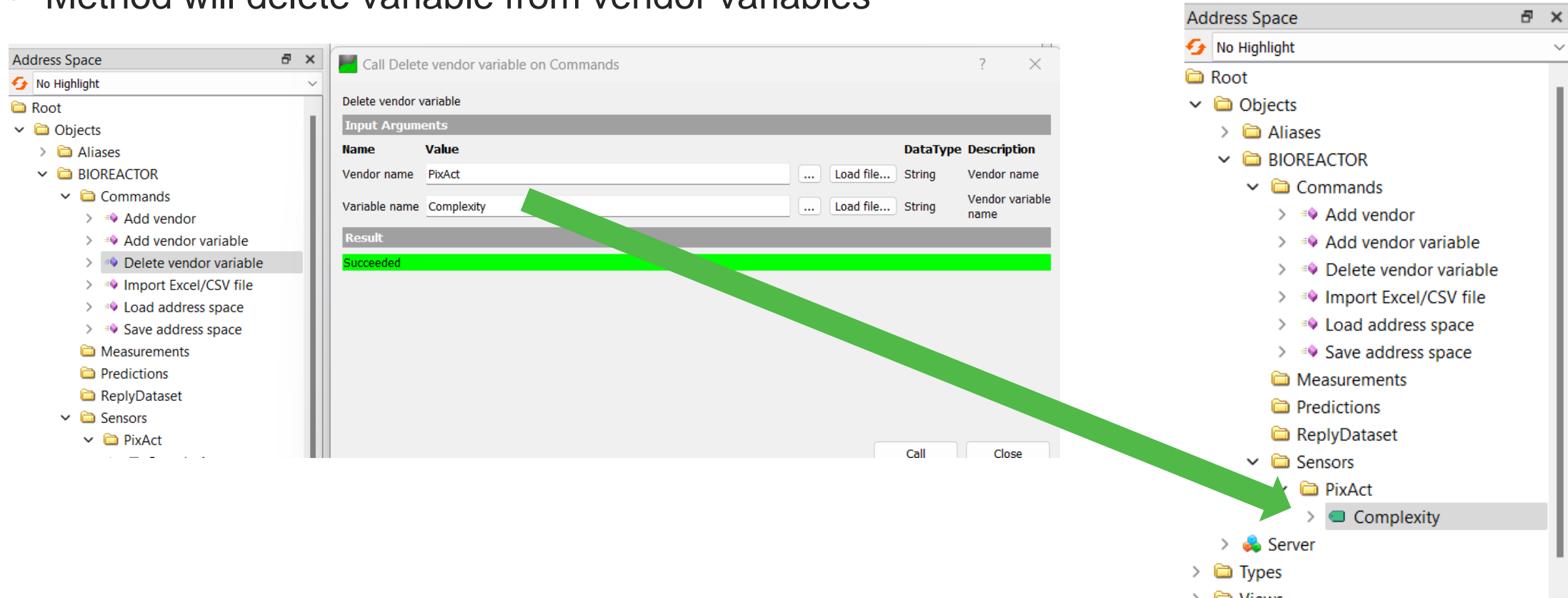
- Method will add variable for vendor, basic OPC UA type supported



Screenshot from the Bioreactor Digital Twin OPC UA Server

BIOREACTOR Server: Delete vendor variable

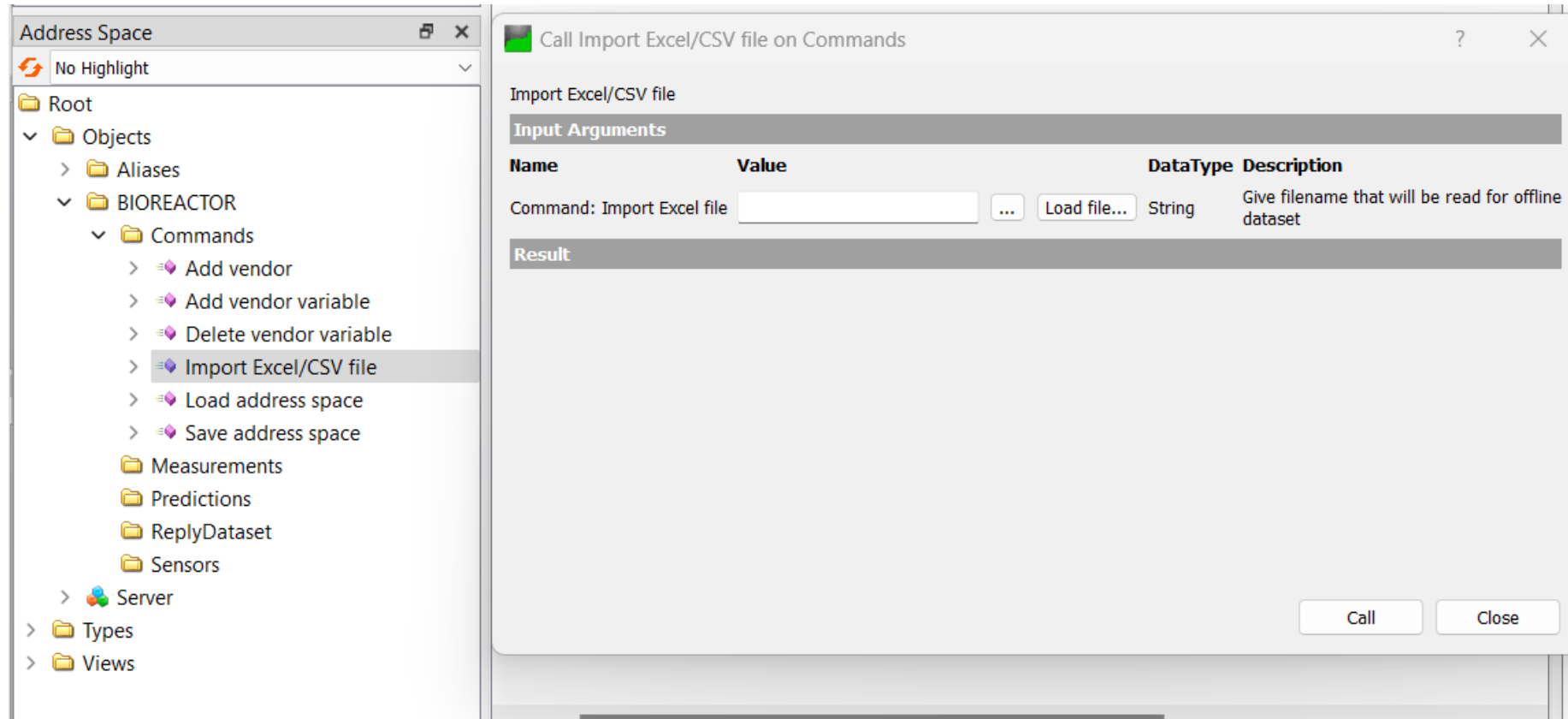
- Method will delete variable from vendor variables



Screenshot from the Bioreactor Digital Twin OPC UA Server

BIOREACTOR Server: Import Excel file

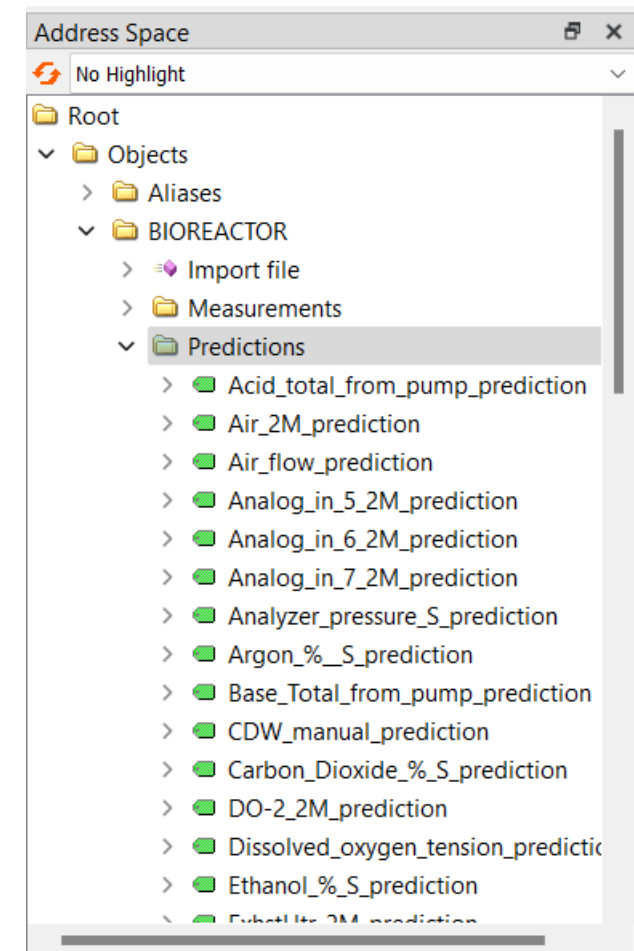
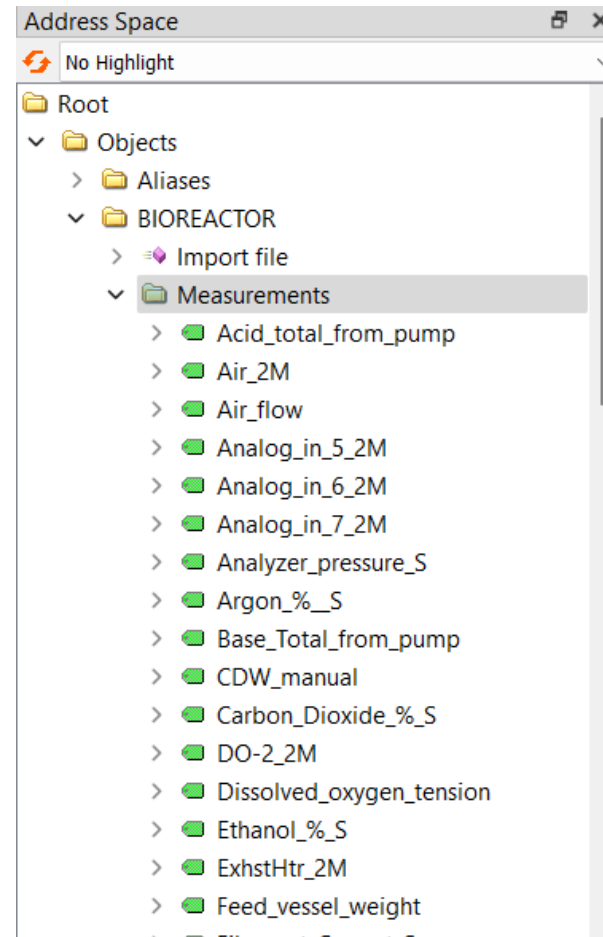
- Method will read file and store dataset (Pandas) into the server memory for the Replay



Screenshot from the Bioreactor Digital Twin OPC UA Server

BIOREACTOR Server: Measurements & predictions variables created into the address space

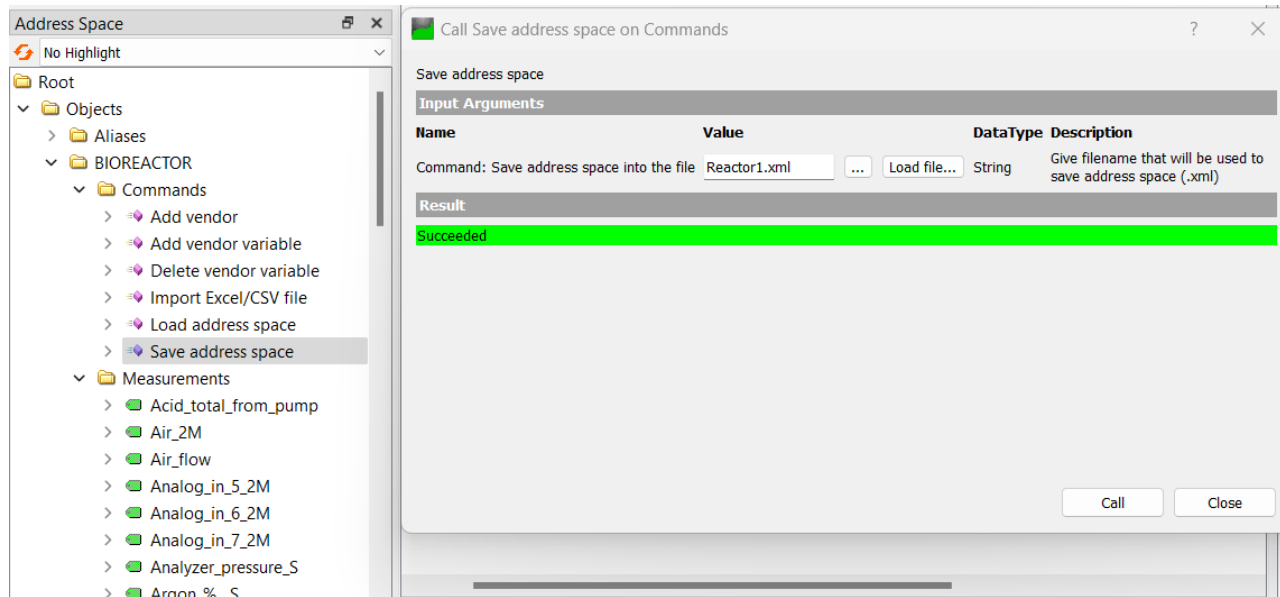
- As Excel file is read all needed variables are created under Measurements & Predictions folders
- Variables are historized into the history.sql (delete file to clear history)



Screenshot from the Bioreactor Digital Twin OPC UA Server

BIOREACTOR Server: Save address space (into the file)

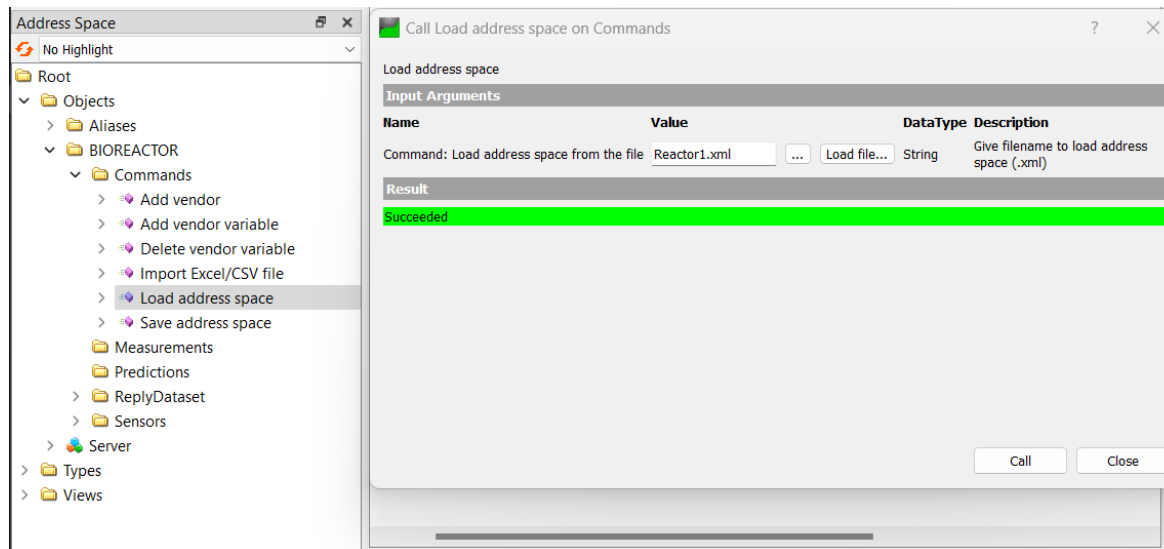
- Import Excel to get all needed Measurements into the address space
- Then add vendors and vendor variables for the specific Reactor
- Save address space to use it later again
- Use case: Different Reactors with same Sensors (reuse address space)



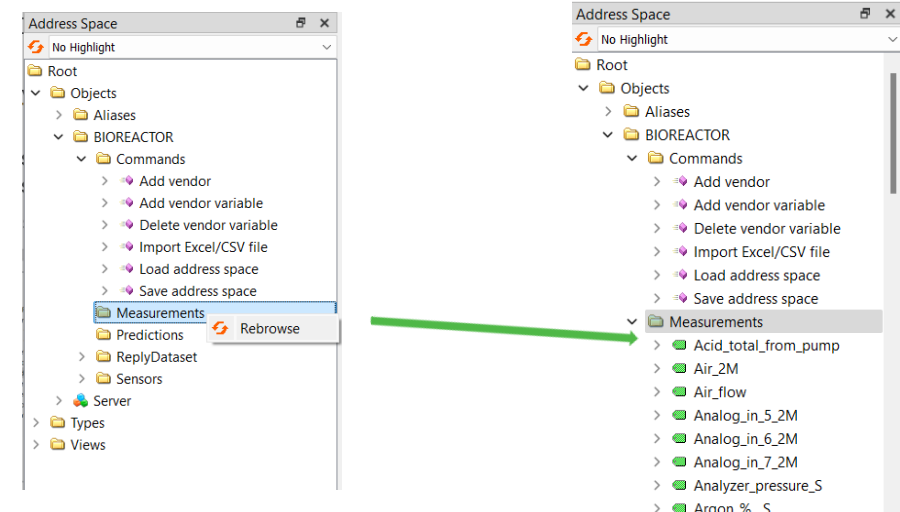
Screenshot from the Bioreactor Digital Twin OPC UA Server

BIOREACTOR Server: Load address space (from the file)

- You must start server and then load needed file (XML format)
- This will load for example all Measurements, Predictions and vendors under Sensors folder with vendor specific variables into the address space (no need to Import Excel / Add vendor variables)
- Use case: Different Reactors with same Sensors (reuse address space)



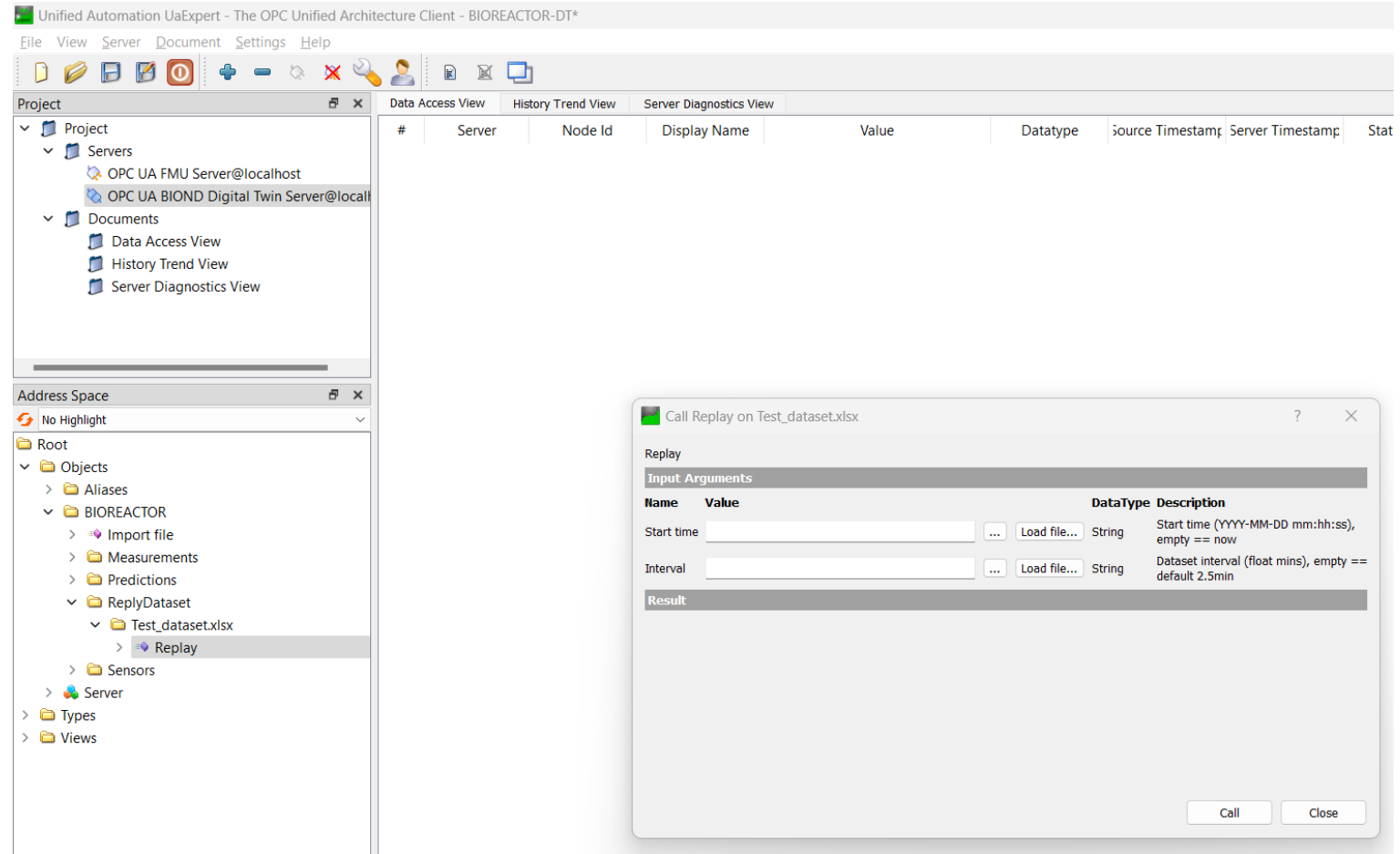
NOTE: You need to **Rebrowse** folder to see variables



Screenshot from the Bioreactor Digital Twin OPC UA Server

BIOREACTOR Server: Replay – load values to variables

- Replay will store values into the history, so trends are available
- Client(s) can use read_raw_history to retrieve values for the forecast model fit
- Forecast client(s) can write values under variables under Predictions folder variable
- Prediction variables are in their own namespace index and each variable has suffix
`ns=3;s=VariableName_prediction`



Screenshot from the Bioreactor Digital Twin OPC UA Server

BIOREACTOR Server: Values loaded from the current time to the end of recorded time

Unified Automation UaExpert - The OPC Unified Architecture Client - BIOREACTOR-DT*

FileViewServerDocumentSettingsHelp

Project

Project

Servers

OPC UA FMU Server@localhost

OPC UA BIOND Digital Twin Server@localhost

Documents

Data Access View

History Trend View

Server Diagnostics View

Address Space

No Highlight

Root

Objects

Aliases

BIOREACTOR

Import file

Measurements

Predictions

ReplyDataset

Test2_dataset.xlsx

1.StartTime

2.EndTime

3.LoadingTime

4.Variables

5.Values

Replay

Sensors

Server

Types

Views

Data Access View

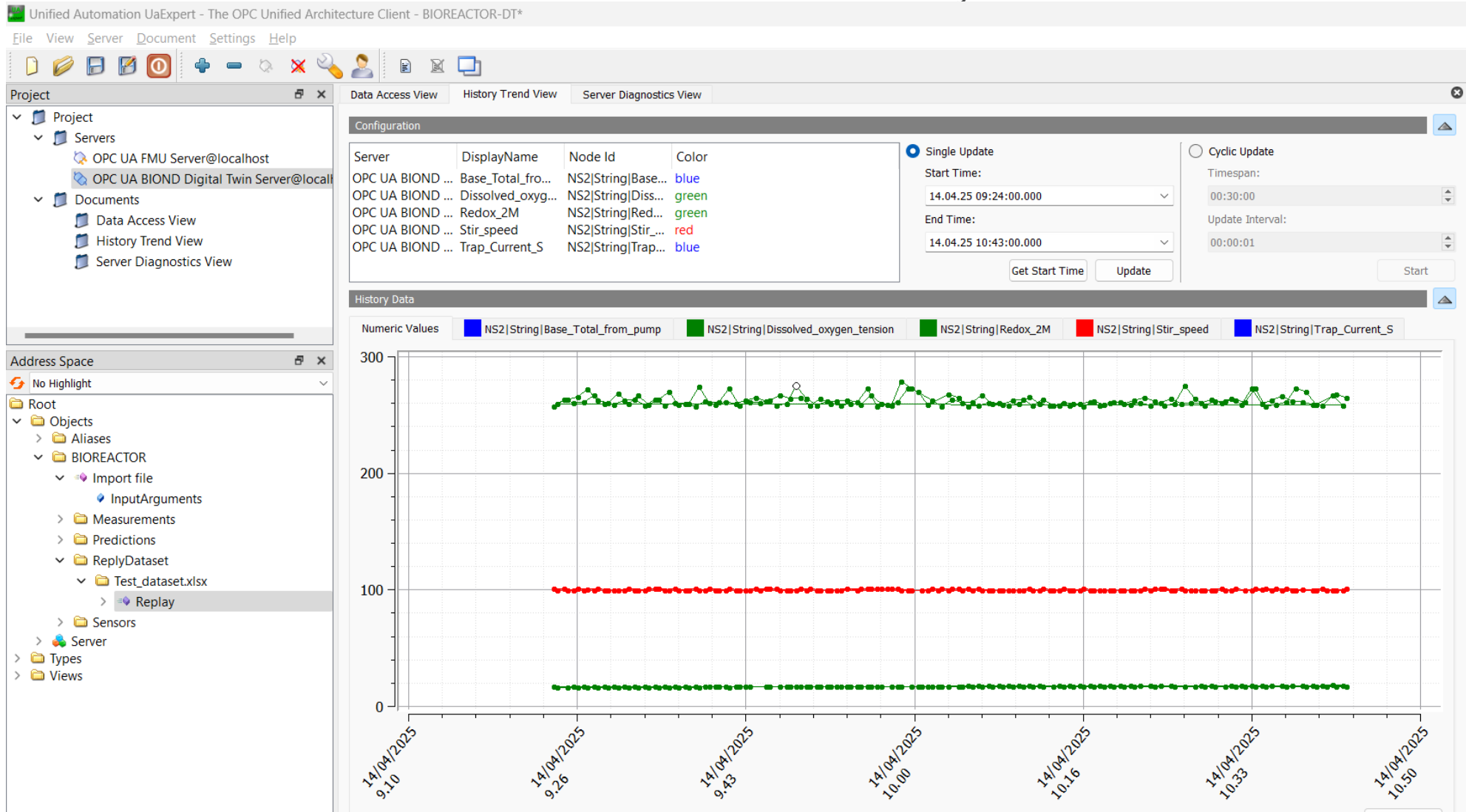
History Trend View

Server Diagnostics View

| # | Server | Node Id | Display Name | Value | Datatype | Source Timestamp | Server Timestamp | Statuscode |
|---|----------------|----------------|---------------|----------------------------|----------|------------------|------------------|------------|
| 1 | OPC UA BION... | NS2[String]... | 1.StartTime | 2025-04-15 14:59:25.481729 | String | 15.02 | 15.02 | Good |
| 2 | OPC UA BION... | NS2[String]... | 2.EndTime | 2025-04-18 22:18:25.481729 | String | 15.02 | 15.02 | Good |
| 3 | OPC UA BION... | NS2[String]... | 3.LoadingTime | 0:02:46.200967 | String | 15.02 | 15.02 | Good |
| 4 | OPC UA BION... | NS2[String]... | 4.Variables | 48 | Int32 | 1.18 | 15.02 | Good |
| 5 | OPC UA BION... | NS2[String]... | 5.Values | 4758 | Int32 | 1.18 | 15.02 | Good |

Screenshot from the Bioreactor Digital Twin OPC UA Server

BIOREACTOR Server: Data can be studied with History Trend view

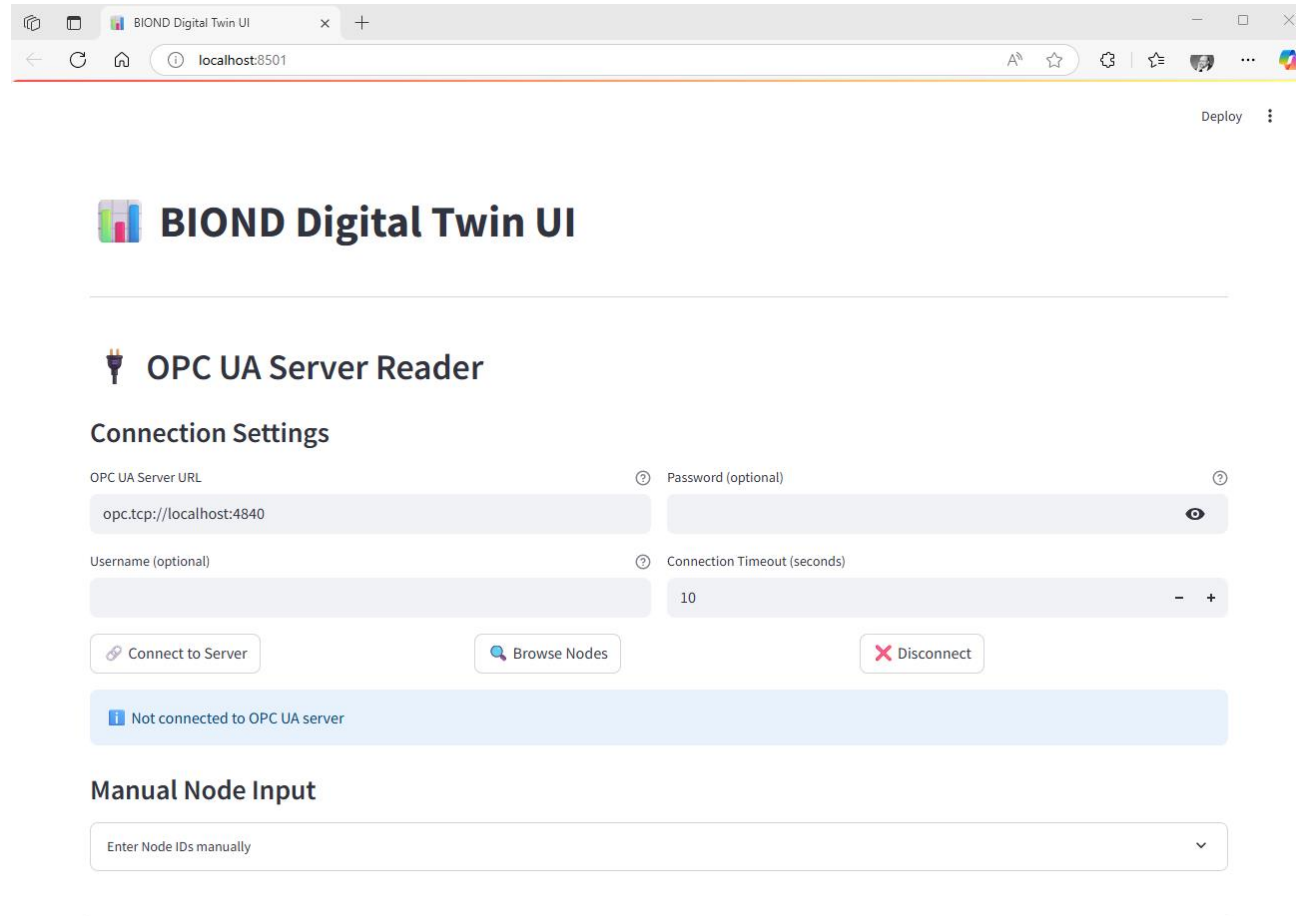


Next steps – actions & vision

- FMI server connected with OPC UA client to rerun offline demo with forecasts
 - Waiting for feedback and results from Aalto
- Another forecast model / algorithm to rerun demo
 - AutoTS / Prophet not giving good / exact results
 - TimesNet or N-BEATS with some time series tuning next candidate
- More data to rerun tests and find better Digital Twin model for forecasting
- Proto-typing web server UI (Streamlit based)
- Vision:
 - Federated learning as one solution to tune actual model

Web server UI – OPC UA Server parameters

Streamlit based proto-type



BIOND Digital Twin UI

OPC UA Server Reader

Connection Settings

OPC UA Server URL:

Password (optional):

Username (optional):

Connection Timeout (seconds):

[Connect to Server](#) [Browse Nodes](#) [Disconnect](#)

Not connected to OPC UA server

Manual Node Input

Web server UI – Connected to OPC UA Server

BIOND Digital Twin UI

OPC UA Server Reader

Connection Settings

| | |
|---|---|
| OPC UA Server URL | Password (optional) |
| <input type="text" value="opc.tcp://localhost:4840"/> | <input type="password" value=""/> |
| Username (optional) | Connection Timeout (seconds) |
| <input type="text" value=""/> | <input type="text" value="10"/> |
| <input type="button" value="Connect to Server"/> | <input type="button" value="Browse Nodes"/> |
| <input type="button" value="Disconnect"/> | |

✓ Successfully connected to OPC UA server!

✓ Connected to OPC UA server

Manual Node Input

Web server UI – Browsing variables under ns=2;s=BIOREACTOR

BIOND Digital Twin UI

OPC UA Server Reader

Connection Settings

OPC UA Server URL ? Password (optional) ?

opc.tcp://localhost:4840

Username (optional) ? Connection Timeout (seconds)

10 - +

✓ Found 96 variable nodes

✓ Connected to OPC UA server

Available Nodes


Select nodes to read/monitor: ?


Choose an option ▼

Manual Node Input

Enter Node IDs manually ▼

Web server UI – Selecting variable(s)

 **BIOND Digital Twin UI**

 **OPC UA Server Reader**

Connection Settings

OPC UA Server URL

opc.tcp://localhost:4840

Password (optional)

Username (optional)

Connection Timeout (seconds)

10

Connect to Server

Browse Nodes

Disconnect

Found 96 variable nodes

Connected to OPC UA server

Available Nodes

Select nodes to read/monitor:

Choose an option

Acid_total_from_pump (ns=2;s=Acid_total_from_pump)

Air_flow (ns=2;s=Air_flow)

Base_Total_from_pump (ns=2;s=Base_Total_from_pump)

Dissolved_oxygen_tension (ns=2;s=Dissolved_oxygen_tension)


Feed_vessel_weight (ns=2;s=Feed_vessel_weight)


pH (ns=2;s=pH)

Pressure (ns=2;s=Pressure)

Refractometer_Brix (ns=3;s=Refractometer_Brix)

Web server UI – Single Read variable(s)

 **BIOND Digital Twin UI**

 **OPC UA Server Reader**

Connection Settings

OPC UA Server URL ⓘ
opc.tcp://localhost:4840

Password (optional) ⓘ

👁

Username (optional) ⓘ

Connection Timeout (seconds) ⓘ
10

- +

🔗 Connect to Server

🔍 Browse Nodes

❌ Disconnect

✅ Connected to OPC UA server

Available Nodes

Select nodes to read/monitor: ⓘ

Acid_total_from... x

⊕ ▼

Reading Mode:
Continuous Read ▼

Read count (interval 1s)
10

- +

📖 Read Values


🔄 Start Continuous Reading


✅ Read 1 values from OPC UA server

📘 Continuous reading would start here. For a full implementation, consider using Streamlit's session state with threading or implement a proper real-time dashboard.



✅ Read 10 values from OPC UA server


Web server UI – Continuous Read variable(s)

 **BIOND Digital Twin UI**


 **OPC UA Server Reader**

Connection Settings


OPC UA Server URL  Password (optional) 




Username (optional)  Connection Timeout (seconds)
 10 - +

Connect to Server Browse Nodes Disconnect

 Connected to OPC UA server


Available Nodes


Select nodes to read/monitor: 


Acid_total_from...   

Reading Mode: Continuous Read Read count (interval 1s)
Continuous Read 10 - +

Read Values Start Continuous Reading

 Read 1 values from OPC UA server

 Continuous reading would start here. For a full implementation, consider using Streamlit's session state with threading or implement a proper real-time dashboard.

 Read 10 values from OPC UA server

Web server UI – Monitor variable(s)

BIOND Digital Twin UI

OPC UA Server Reader

Connection Settings

OPC UA Server URL ? Password (optional) ?

opc.tcp://localhost:4840

Username (optional) ? Connection Timeout (seconds)

10 - +

☒ Connected to OPC UA server

Available Nodes

Select nodes to read/monitor: ?

Acid_total_from... x

Reading Mode: ?

Monitoring Interval (ms)

Monitor 100 1000 5000

☒ Read 1 values from OPC UA server

☒ Read 10 values from OPC UA server

Continuous reading would start here. For a full implementation, consider using Streamlit's session state with threading or implement a proper real-time dashboard.

Web server UI – OPC UA Data and Real-time Trends

Manual Node Input

Enter Node IDs manually

OPC UA Data

OPC UA Server Data

Rows

Columns

Memory Usage

16

5

3.5 KB

| | timestamp | node_id | display_name | value | data_type |
|----|---------------------|-----------------------------|----------------------|-------|-----------|
| 1 | 2025-05-27 15:36:47 | ns=2;s=Acid_total_from_pump | Acid_total_from_pump | 15.3 | float |
| 2 | 2025-05-27 15:36:48 | ns=2;s=Acid_total_from_pump | Acid_total_from_pump | 15.3 | float |
| 3 | 2025-05-27 15:36:49 | ns=2;s=Acid_total_from_pump | Acid_total_from_pump | 15.3 | float |
| 4 | 2025-05-27 15:36:50 | ns=2;s=Acid_total_from_pump | Acid_total_from_pump | 15.3 | float |
| 5 | 2025-05-27 15:36:51 | ns=2;s=Acid_total_from_pump | Acid_total_from_pump | 15.3 | float |
| 6 | 2025-05-27 15:36:52 | ns=2;s=Acid_total_from_pump | Acid_total_from_pump | 1.5 | float |
| 7 | 2025-05-27 15:36:53 | ns=2;s=Acid_total_from_pump | Acid_total_from_pump | 1.5 | float |
| 8 | 2025-05-27 15:36:54 | ns=2;s=Acid_total_from_pump | Acid_total_from_pump | 1.5 | float |
| 9 | 2025-05-27 15:36:55 | ns=2;s=Acid_total_from_pump | Acid_total_from_pump | 1.5 | float |
| 10 | 2025-05-27 15:36:56 | ns=2;s=Acid_total_from_pump | Acid_total_from_pump | 1.5 | float |

Data Summary

Export Data

Clear Data

Real-time Trends



Process Variables Trends



Raw Data

Show Recent Data Points

Summary

OPC UA standard as key enabler

- Enables interoperability between different vendors and actors
- Tests can be rerun with different simulation/prediction models
- Real-time data can be used with historical data
- Different user interfaces for needed use case:
 - Monitor values
 - Compare model and prediction values to validate model
- Vision:
 - Control actual Bioreactor with model predictions, write setpoints to actual controller

