WP1.2:
Model Predictive Control

WP Leader: Lieve Helsen
Master of ceremony: David Blum

Digital Expert Meeting
October 13, 2020

THE GOALS

Using Modelica,

an equation-based object-oriented modelling language

1. To develop an open-source **Library for MPC**
2. To develop a **framework** to test and assess MPC performance
3. To compare and **benchmark** different **MPC formulations**

THE WORK PLAN

WP1.2 Model Predictive Control (MPC)

Task 1.2.1:
Develop a framework to test and assess MPC performance

Taks 1.2.2:
Compare and benchmark MPC algorithms

Task 1.2.3:
Develop a Modelica library for MPC

THE ACTION PLAN DEFINED IN MAY 2020

Focus points defined for the period after the May 2020 digital meeting:

- **Virtual Testing Framework (BOPTEST):**
  - Continued development and prototype testing, start testing first controllers, reporting
  - MPC contest targeted for 2022
- **Emulator Models:**
  - Further development, documentation and review (peer review document)
  - Need for case with intermediate complexity: BESTEST Hydronic with modulating heat pump to see the effect of exploiting flexibility
- **Robustness towards uncertainties**
  - Start with uncertainties on weather predictions

THE WP1.2 TEAM

17 participants from 9 institutes/companies

Affiliation	Team members
KU Leuven	Lieve Helsen, Filip Jorissen, Javier Arroyo, Iago Cupeiro
LBNL	David Blum, Michael Wetter
ENGIE Lab	Valentin Gavan
SDU	Toa Yang, Konstantin
PNNL	Huang Sen, Jan Drgona, Chen Yan
IK4 Tekniker	Jesus Febres, Aritz Bengoetxea → Laura Zabala
SINTEF	Harald Tax Walnum
Politecnico de Milano	Ettore Zanetti
ORNL	Yeonjin Bae

STATUS WORK

Coordination meetings since May
3 Monthly progress meetings

Chaired by Lieve Helsen

When?
June 1, July 15, September 9

What?

1. Progress and discussions on emulators, KPIs & scenarios, BOPTEST, MPC Library
2. Dissemination and joint papers
3. Next phase
4. Miscellaneous

STATUS WORK

Task 1.2.1: Development of a framework to test and assess MPC performance BOPTEST

Virtual test bed - Architecture which allows control by whatever controller

- ✓ BOPTEST Workflow for use cases, prototype and documentation: ready (https://github.com/ibpsa/project1-boptest)
- ✓ Ongoing developments:
  - ✓ parameterize and implement **forecast errors** – internal working group generalizing forecast error model(s) with real forecasted and measured data, now focusing on weather prediction uncertainty using autoregressive models and Q-Q mapping.
  - ✓ define **workflow for training data for grey-black-box models** different than testing data – use TMYx and TMY3, one for training and the other for testing
  - ✓ Continuous **maintenance and feature enhancements**, e.g. new version Docker container that uses Python 3 and PyFMI (no JModelica-compiled image needed), update of parser

STATUS WORK

Task 1.2.1: Development of a framework to test and assess MPC performance BOP-TEST

Virtual test bed - Detailed emulator models

- ✓ Modelica template/guidelines for standardizing towards KPIs and inputs/outputs communication: ready
- ✓ Peer review process by checklists (v1.0, 1.1, 1.2) and unit tests (in BOPTEST repository, using the whole BOPTEST toolchain): ready
- ✓ Emulators (in BOPTEST repository - directory Testcases): development, documentation and review: from 10 to 12, nicely progressed – see next slide

Emulator	Developer
Single-zone BESTEST hydronic	Filip & Javier
Single-zone BESTEST hydronic (modulating HP)	Javier & Filip
Single-zone BESTEST air-based (gas boiler)	Dave
Multi-zone (8z) residential hydronic heating (gas boiler)	Valentin & Javier
Multi-zone (8z) residential hydronic heating + air cooling	Valentin
Single-zone commercial air-based	Dave
Single-zone commercial hydronic	Krzysztof / Tao
Multi-zone (5z) commercial air-based	Dave
Multi-zone office hybrid (simple)	Iago & Javier
Multi-zone office hybrid (complex)	Filip
Multi-zone commercial air-based	Yeonjin
Multi-zone prototype air-based (complex)	Sen Huang

- Merged to master. **Ready!**
- In pull request
  → Under peer-review (working on latest changes and documentation)
- In pull request
  → BOPTEST additions needed (like IO blocks, test case data or unit-tests)
- In pull request
  → Model changes needed
- Emulator model under development

STATUS WORK

Task 1.2.2: Comparison and benchmarking MPC algorithms

Virtual test bed developed in Task 1.2.1 is used to **test MPC formulations and solvers** on common emulators, which allows benchmarking the MPC algorithms using selected performance indicators

- ✓ MPC description template: ready
- ✓ Core KPIs quantification - calculation module: ready
- ✓ Use of **representative days/weeks**: ongoing
- ✓ List of **scenarios** to vary boundary conditions (e.g. weather, price profile energy vectors (consistent with emission factors), uncertainty on forecast …): ongoing
- ✓ **Internal testing**: ongoing
- ✓ Internal (spreadsheet) and public (centralized location) **reporting**: to be discussed

STATUS WORK

MPC contest: targeted for 2022

STATUS WORK

Task 1.2.3: Development of a Modelica library for MPC

Library of models that can be used to efficiently solve optimal control problems for building and district energy systems (& that can be combined with parameter and state estimation algorithms)

- ✓ Development of framework on first small models for unit testing: ongoing
- ✓ Development of guidelines for library use – like modelica-ibpsa wiki: to be started

STATUS WORK

Publications

- MPC Review paper published in journal

  Thanks Jan for taking the lead here!

  Ján Drgoňa, Javier Arroyo, Iago Cupeiro Figueroa, David Blum, Krzysztof Arendt, Donghun Kim, Enric Perarnau Ollé, Juraj Oravec, Michael Wetter, Draguna L. Vrabie, Lieve Helsen (2020)

  All you need to know about model predictive control for buildings

  Annual Reviews in Control
  available on-line
  https://authors.elsevier.com/sd/article/S1367-5788(20)30058-4

STATUS WORK

Publications

- BS2021 abstracts accepted
  - Javier Arroyo, Carlo Manna, Fred Spiessens, Lieve Helsen ‘Reinforced Model Predictive Control for Building Energy Management’
  - Iago Cupeiro Figueroa, Lieve Helsen ‘A low-order semi-physical borefield model for optimal control applications’
  - Filip Jorissen, Damien Picard, Lieve Helsen ‘Automated workflows for optimal design and control of buildings using Modelica’

BREAKOUT SESSIONS

	Content - title	Presenter/Leader	time
Session 1 (Day 1)	**BOPTEST: benchmarking and reporting**		**50 min**
	Presentation of results of first tests	Dave/Javier/Filip/PNNL/...	20 min
	Spreadsheet for internal reporting of BOPTEST test cases	Javier	15 min
	Public reporting (limited information, end-user agreement)	NREL/Dave	15 min
Session 2 (Day 1)	**Data and predictions**		**55 min**
	Generating weather data for training grey/black box models	David Blum/Yan Chen	20 min
	Dealing with uncertainties - weather prediction	Laura	15 min
	Dealing with uncertainties - loads & occupancies	All	10 min
	Issues related to emulators	All	10 min
Session 3 (Day 2)	**New developments**		**45 min**
	Multi-objective Deep Reinforcement Learning Control (MODRLC) project	Nick, Sourav, Thibault	10 min
	Data-driven approaches – opportunities for MPC and BOPTEST?	Jan Drgona	15 min
	New developments in BOPTEST	David Blum	15 min
	MPC Library	Filip Jorissen	5 min
Session 4 (Day 2)	**Outreaching**		**45 min**
	MPC competition: how to set up?	All	20 min
	Workshop introducing BOP-TEST at BS2021?	All	20 min
	Initiatives for joint papers	All	5 min

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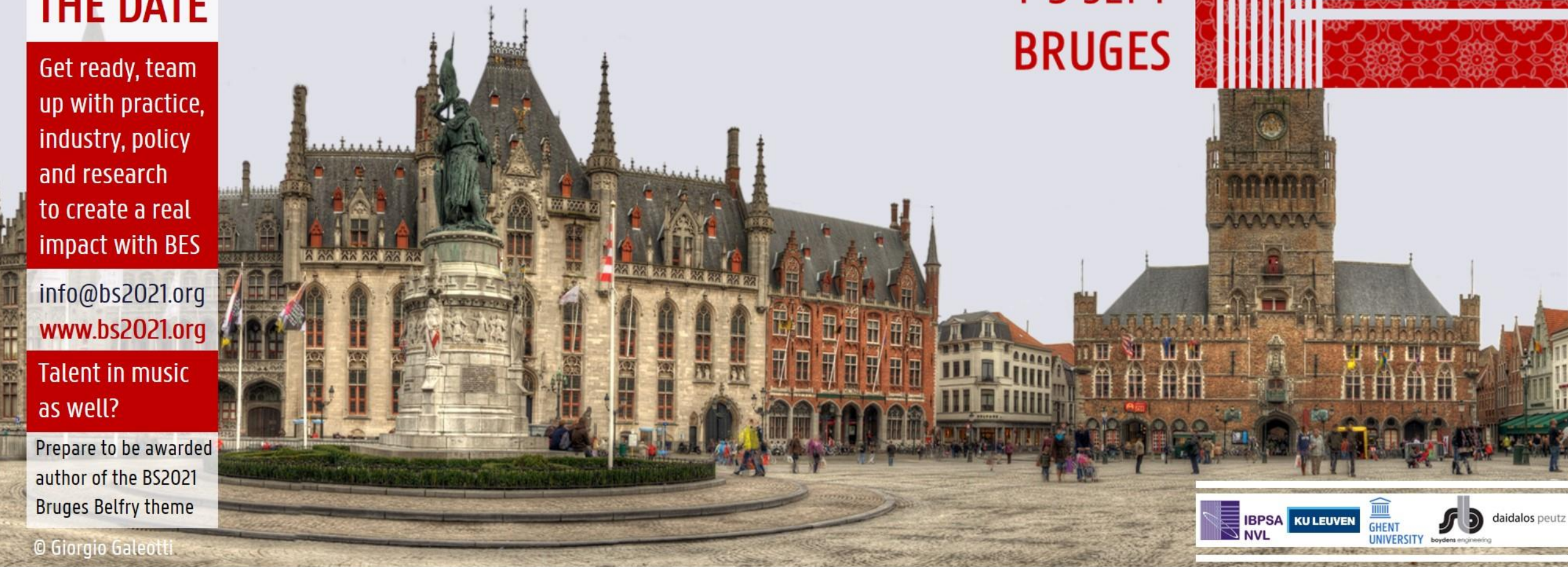

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