THE AMERICAN MODELICA 2024 CONFERENCE

STORRS
OCTOBER 14-16

Modelica Language

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WELCOME

We are looking forward to gathering with you once again as the North American Modelica community at this new edition of the conference this year. While we have all learned a great deal through our experiences during the pandemic, a new appreciation of the importance of face-to-face interaction is a common refrain that is echoed by many in our personal and professional circles. Aren't the chats at the coffee breaks just as valuable as the formal presentations? In my experience, coffee break talk has often provided deep insights, lively debates, and great ideas for future research topics.

We see this event also as a great opportunity to connect the Modelica community across continents. Fortunately for us, quite a few presenters are coming from Europe. As usual, we are also going to update everybody on the latest news from the community, as well as ongoing Modelica-related research.

It is great to return to the University of Connecticut in Storrs after having been here already once 8 years ago in 2016. This year's event will be held at the new and well-equipped Innovation Partnership Center at UConn Tech Park. We'd like to extend our deep appreciation and thanks to Prof. George Bollas and Janesa Mackin from the University of Connecticut for hosting and coordinating this year's event. The new facilities are great and are nicely equipped to handle live streaming and the recording of all talks.

The conference comes at a perfect time to enjoy the fall colors of the leaves in New England. Storrs is surrounded by forests; you should seize the opportunity to take a hike in the area. A warm welcome to all of you at the American Modelica Conference 2024!

Hubertus Tummescheit
Conference Co-chair

Modelica Language

CONFERENCE DETAILS:

The conference will take place at the Innovation Partnership Building at the University of Connecticut Tech Park on Tuesday and Wednesday, October 15 and 16. The locations of the vendor tables and lunch are indicated on the maps on page 8 of this program.

CONFERENCE ADDRESS:
Innovation Partnership Building, 159 Discovery Drive
Storrs, CT 06269.

Directions are available at **https://techpark.uconn.edu/contact/** or via other internet mapping services.

CONFERENCE PRESENTATIONS:
The presentations on Tuesday and Wednesday, October 15 and 16, will all take place on the third floor in room 317.

CONFERENCE WEBSITE:
https://modelica.org/events/american2024/

All updated conference information can be found at the website, including conference papers and abstracts.

WORKSHOP ADDRESS:
The workshops will take place on Monday, October 14 in rooms 203 (on the second floor), 317, and 323 (on the third floor). Specific room assignments will be made and communicated via the conference web page prior to the conference in response to the number of attendees for each workshop.

EMERGENCY INFORMATION:
To report an emergency, call 9-1-1, or call the UConn Police Department at 860-486-4800.

INTERNET/WIFI:
The SSID is UCONN-GUEST; you have to register and agree to the terms and conditions to log into the network.

REGISTRATION DESK:
The registration desk is open in the 2nd floor lobby from Tuesday, October 15 at 7:00 am through the duration of the conference.

TOURIST INFORMATION:
UConn offers a variety of entertaining and exciting attractions to tourists. The campus is home to a museums covering a variety of interests, including a celebration of Huskymania at the J. Robert Donnelly Husky Heritage Sports Museum, the Ballard Institute and Museum of Puppetry, and the William Benton Museum of Art, Connecticut's state art museum. The award-winning UConn Dairy Bar also features 24-plus flavors of delicious ice cream made from our own cows' milk, and adjacent to the campus is Downtown Storrs, a vibrant retail and residential college center featuring shops, museums, restaurants for every craving, a grocery store, and more. Additional information for visiting UConn and Connecticut is available at https://admissions.uconn.edu/visit/storrs-main-campus/plan/ and https://ctvisit.com/.

PARKING:
The Innovation Partnership building has two large parking lots adjacent to it that will be available for use during the conference. Parking passes will be required to avoid ticketing during the day, and passes will be distributed to the attendees when they check in during registration upon request. For those attendees who are staying at the Graduate Storrs hotel, cars may be left in the hotel parking lot and attendees may use the campus bus system to simplify travel between the hotel and conference location. The Passio GO app (available from app stores) is used to ascertain bus schedules and pickup times.

DAY 1: 14 OCTOBER 2024

10:00 AM – 1:00 PM	Workshops in rooms 203, 317, 323; please see conference webpage for more information.
1:00 PM – 2:00 PM	Lunch Break
2:00 PM – 5:00 PM	Workshops in rooms 203, 317, 323; please see conference webpage for more information.

DAY 2: 15 OCTOBER 2024 ROOM 317

7:00 AM – 8:30 AM	Arrival/Welcome
8:30 AM – 10:15 AM	Vendor Sessions
10:15 AM – 11:00 AM	Modelica Association/FMI updates
11:00 AM – 12:00 PM	Keynote 1
12:00 PM – 1:00 PM	Lunch
1:00 PM – 2:00 PM	Thermofluid Systems 1
2:00 PM – 3:00 PM	Language/Tools 1
3:00 PM – 3:30 PM	Coffee Break
3:30 PM – 4:30 PM	Power Systems
4:30 PM – 5:30 PM	Language/Tools 2
5:30 PM – 6:00 PM	Transit to Graduate Storrs
6:00 PM – 10:00 PM	Conference Dinner

DAY 3: 16 OCTOBER 2024 ROOM 317

8:30 AM – 9:30 AM	Keynote 2
9:30 AM – 10:00 AM	Coffee Break
10:00 AM – 11:00 AM	Thermofluid Systems 2
11:00 AM – 12:00 PM	Electromechanical Systems
12:00 PM – 1:00 PM	Lunch
1:00 PM – 2:00 PM	Language/Tools 3
2:00 PM – 3:00 PM	User Presentations 1
3:00 PM – 3:30 PM	Coffee Break
3:30 PM – 4:10 PM	Thermofluid Systems 3
4:10 PM – 5:00 PM	User Presentations 2
5:00 PM – 5:30 PM	Podium Discussion

Schedule provided in Eastern Daylight Time (UTC-4)

DAY 1

ROOM 1

10:00 AM – 1:00 PM

Workshop: Introduction to Modeling, Simulation, Debugging, and Interoperability with Modelica and OpenModelica

Lena Buffoni, Linköping University

ABSTRACT: This tutorial gives an introduction to the Modelica language, the OpenModelica environment, and an overview of modeling and simulation in a number of application areas. Some advanced features of OpenModelica will be presented. A number of hands-on exercises will be done during the tutorial, both graphical modeling using the Modelica standard library and textual modeling. Please bring your laptop for exercises.

EXPECTED EXPERIENCE: Basic level for Modelica, Python, and FMI.

SOFTWARE REQUIREMENT: Laptop with Windows, Linux or Mac.

ADDITIONAL INFORMATION: https://www.ida.liu.se/~adrpo33/AmericanModelica2024/

2:00 PM – 5:00 PM

Workshop: Introduction to Modelica and Thermo-fluid Modeling with Applications from the Buildings Library

Michael Wetter, David Blum, Hongxiang Fu

ABSTRACT: This workshop will give an introduction to the modeling of thermo-fluid systems and their control using Modelon Impact and the Modelica Buildings Library. We will be using applications from the Modelica Buildings Library, but the course will be structured to also appeal to modelers from other application domains that are concerned with thermo-fluid systems. After an introductory presentation that discusses the scope of the Modelica Buildings Library, we discuss best practices in setting up thermo-fluid flow models and how to avoid potential problems. In hands-on exercises, participants will build models of simple heating and air conditioning systems, link them to a thermal load, and add feedback control. The models will be built using components from the Modelica Buildings Library. Simulations will be run on OpenModelica and Modelon Impact.

EXPECTED EXPERIENCE: Prior knowledge of Modelica and first experience with OpenModelica's OMEdit or Modelon's IMPACT, or watch the online tutorial at https://help.modelon.com/latest/application_overview/getting_started_overview/.

SOFTWARE REQUIREMENT: Laptop with recent version of either Google Chrome or Opera installed. 8GB of memory is recommended.

ADDITIONAL INFORMATION: https://simulationresearch.lbl.gov/modelica/training.html

ROOM 2

10:00 AM – 1:00 PM

Workshop: Integrating Declarative and Imperative Acausal Modeling with ModelingToolkit

Chris Rackauckas, Brad Carman

ABSTRACT: Modelica and JuliaSim Modeling Language (JSML) are designed to work as declarative acausal modeling systems. ModelingToolkit hits an interesting middle ground in the design space of modeling systems by having declarative semantics which are interacted with imperatively. In this workshop we will explore this idea by demonstrating some of the ergonomic advantages gained by such an approach. Computer generation of model variations for more easily comparing between models, data-driven generation of models via symbolic regression and evolutionary approaches, and non-standard model transformations (moment closure approximations) will be used to showcase how the interactivity of the ModelingToolkit compiler can be used to improve modeling workflows. The disadvantages will also be discussed, in particular the difficulties of certain analyses and GUI integration. Altogether, participants will get a better view of the engineering trade-offs being explored in the modeling and simulation space and leave with a better perspective of alternative modeling workflows.

The workshop will start with a quick introduction to ModelingToolkit itself (https://docs.sciml.ai/ModelingToolkit/stable/). Then, some of the examples from the ModelingToolkit Course (https://sciml.github.io/ModelingToolkitCourse/dev/lectures/lecture2/) will be used in order to highlight some of the computational generation of models. Automated model generation (https://docs.sciml.ai/Overview/stable/showcase/missing_physics/) will also be highlighted.

EXPECTED EXPERIENCE: Only Modelica experience is required.

SOFTWARE REQUIREMENT: A computer that can install Julia.

2:00 PM – 5:00 PM

Workshop: Deployment of Models as Web-Apps with Modelon Impact

Hubertus Tummescheit, Lixiang Li

ABSTRACT: In this session you will learn more about a deployment approach that allows custom interfaces to be created for parameterization and post-processing. The course will make use of the Modelon Impact REST-API, documented on https://modelon-impact-client.readthedocs.io/en/latest/, Jupyter notebooks as the app-development environment, and a few utility-routines that will speed up building a web-app. The notebook can be deployed as a web-app through the Voilà framework (https://github.com/voila-dashboards/voila). Participants who know the concepts of Modelica tools should be able to run a simple, self-developed web app on top of Modelon Impact, and understand the possibilities to automate workflows and deploy them as app in Modelon Impact. Pre-reading tutorials are available at https://help.modelon.com/latest/.

EXPECTED EXPERIENCE: Familiarity with any Modelica tool required, familiarity with Modelon Impact beneficial. Some familiarity with Python programming. Participants are encouraged to familiarize themselves with Modelon Impact before the course at https://help.modelon.com/latest/.

SOFTWARE REQUIREMENT: Participants will recieve access to Modelon Impact in the cloud.

ADDITIONAL INFORMATION: https://www.ida.liu.se/~adrpo33/AmericanModelica2024/

ROOM 3

10:00 AM – 1:00 PM

Workshop: Using Python as an Interface for Modelica and the FMI Standard

Behnam Afsharpoya

ABSTRACT: Python is a very well-known coding language with valuable libraries that provide toolboxes for artificial intelligence and machine learning methods. Integration of Python with Modelica and the FMI standard can provide useful toolboxes for physics-based and numerical analyses.

EXPECTED EXPERIENCE: Basic level for Modelica, Python and FMI.

SOFTWARE REQUIREMENT: Python, Modelica and FMI tools will be provided. A C compiler needs to be installed.

DAY 2

1:00 PM – 2:00 PM **Thermofluid Systems 1**

Model-Based Design and Characterization of an Actuator with a Low-Boiling Liquid

Christoph Steinmann, Johannes Herold, Jens Schirmer

Dynamic Modeling Methodology for Near Isothermal Compressor

Haopeng Liu, Vikrant Aute, Yunho Hwang, Chengyi Lee, Jan Muehlbauer, Lei Gao

Fluid Property Functions in Polar and Parabolic Coordinates

Scott Bortoff, Christopher Laughman, Vedang Despande, Hongtao Qiao

2:00 PM – 3:00 PM **Language/Tools 1**

Objectively Defined Intended Uses, a Prerequisite to Efficient MBSE

Erik Rosenlund, Robert Hällqvist, Robert Braun, Petter Krus

Modelica Supported Automated Design

Ion Matei, Maksym Zhenirovskyy, John Maxwell, Saman Mostafavi

Proposal for a Context-Oriented Modelica Contributing to Variable Structure Systems

Zizhe Wang, Manuel Krombholz, Uwe Aßmann, John Tinnerholm, Christian Gutsche, Volodymyr Prokopets, Sebastian Götz

3:30 PM – 4:30 PM **Power Systems**

Building Power System Models for Stability and Control Design Analysis using Modelica and the OpenIPSL

Srijita Bhattacharjee, Luigi Vanfretti, Fernando Fachini

Integrating the IEEE/CIGRE DLL Modeling Standard to Use "Real Code" Models for Power System Analysis in Modelica Tools

Hao Chang, Luigi Vanfretti

Decentralised Hydrogen Fuelled Gas Engine CHP Units: A Feasibility Study with Modelica

Florian Andreas Beerlage, Naqib Salim, Maurice Kettner

4:30 PM – 5:30 PM **Language/Tools 2**

FMI-3.0 Export for Models with Clocks in a Signal Flow Diagram Environment

Masoud Najafi, Ramine Nikoukhah

Event Support for Simulation and Sensitivity Analysis in CasADi for Use with Modelica and FMI

Joel Andersson, James Goppert

Steady-State Optimization of Modelica Models and Functional Mockup Units with Pyomo

Jesse Gohl, Hubertus Tummescheit, Robin Andersson, Matthew Stuber

DAY 3

10:00 AM – 11:00 AM **Thermofluid Systems 2**

Development and Validation of a Water-To-Air Heat Pump Model Using Modelica

Yuhang Zhang, Mingzhe Liu, Zhiyao Yang, Caleb Calfa, Zheng O'Neill

Enhancing COP through Sub-cooling Temperature Control in Dual Heat Pump Systems: A Dynamic Simulation Study using OpenModelica

Zahra Hajabdollahi Ouderji, Zhibin Yu

A Modelica Implementation of an Organic Rankine Cycle

Hongxiang Fu, Ettore Zanetti, Jianjun Hu, David Blum, Michael Wetter

11:00 AM – 12:00 PM **Electromechanical Systems**

Advancements in Building-to-Grid Interactions: Thermo-Electric Coupling Models of Motor-driven Devices

Viswanathan Ganesh, Zhanwei He, Wangda Zuo

Modelica as Model Aggregator for Holistic Architecture Validation of Electric Vehicles

Marcel Gottschall, Torsten Blochwitz, Andreas Abel, Alex Magdanz

Multiphysics Acausal Modeling and Simulation of Satellites Using Modelica Library

Salvatore Borgia, Francesco Topputo

1:00 PM – 2:00 PM **Language/Tools 3**

Advanced Edge Deployment: Abstracting Cyber-Physical Models via FMU Mastery

Fanping Bu, Mikalai Filipau, Nikolay Baklanov

Integrating Generative Machine Learning Models and Physics-Based Models for Building Energy Simulation

Luigi Vanfretti, Christopher Laughman, Ankush Chakrabarty

Pipeline-based Automated Integration and Delivery Testing of Simulation Assets with FMI/SSP in a Railway Digital Twin

Ozan Kugu, Shiyang Zhou, Stefan H. Reiterer, Mario Schwaiger, Lukas Wurth, Manfred Grafinger

2:00 PM – 3:00 PM **User Presentations 1**

A Template-Based Method for Creating Modelica Simulation Models for Whole-Building Electrical Systems

Anay Waghale, Karthikeya Devaprasad, Michael Poplawski, Tianna-Kaye Woodstock, Shat Pratoomratana

Thermal Modeling and Simulation of the Powin Energy Storage System

Cory Dinkle, Erik Durling, John Batteh

Integrated 1D-3D Thermal Design Space Toolset for Energy Management in Electric Vehicles

Amir Doroudian, Ashwin Hariharan, Lucas Phan, Rajaram Maringanti

Motorsport Technology Transfer Deploying Vehicle Simulation to the Masses

Theodor Ensbury, Nate Horn, Isaac Rose

3:30 PM – 4:10 PM **Thermofluid Systems 3**

Thermo-Fluid Modeling Framework for Supercomputer Digital Twins, Part 1: Demonstration at Exascale

Vineet Kumar, Scott Greenwood, Wesley Brewer, David Grant, Nathan Parkison, Wesley Williams

Thermo-Fluid Modeling Framework for Supercomputing Digital Twins, Part 2: Automated Cooling Models

Scott Greenwood, Vineet Kumar, Wesley Brewer

4:10 PM – 5:00 PM **User Presentations 2**

Efficient Simplified Models for District Energy CHP Systems

Zhanwei He, Wangda Zuo

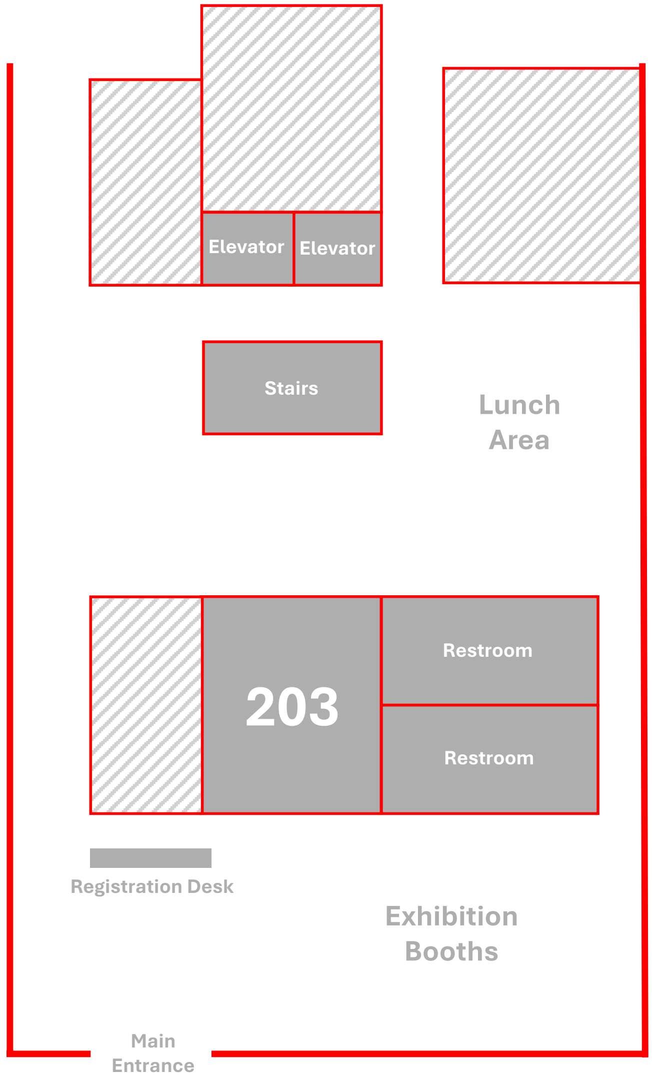
Optimizing Energy Consumption of a Plant-Scale Water-Cooled Central Cooling System via a High-Fidelity Simulator

Myoungsoo Kim, Chanil Chun, Minjun Song, Haeun Yoo, Hyungsik Um, Jiwhan Lee, Sejun Park

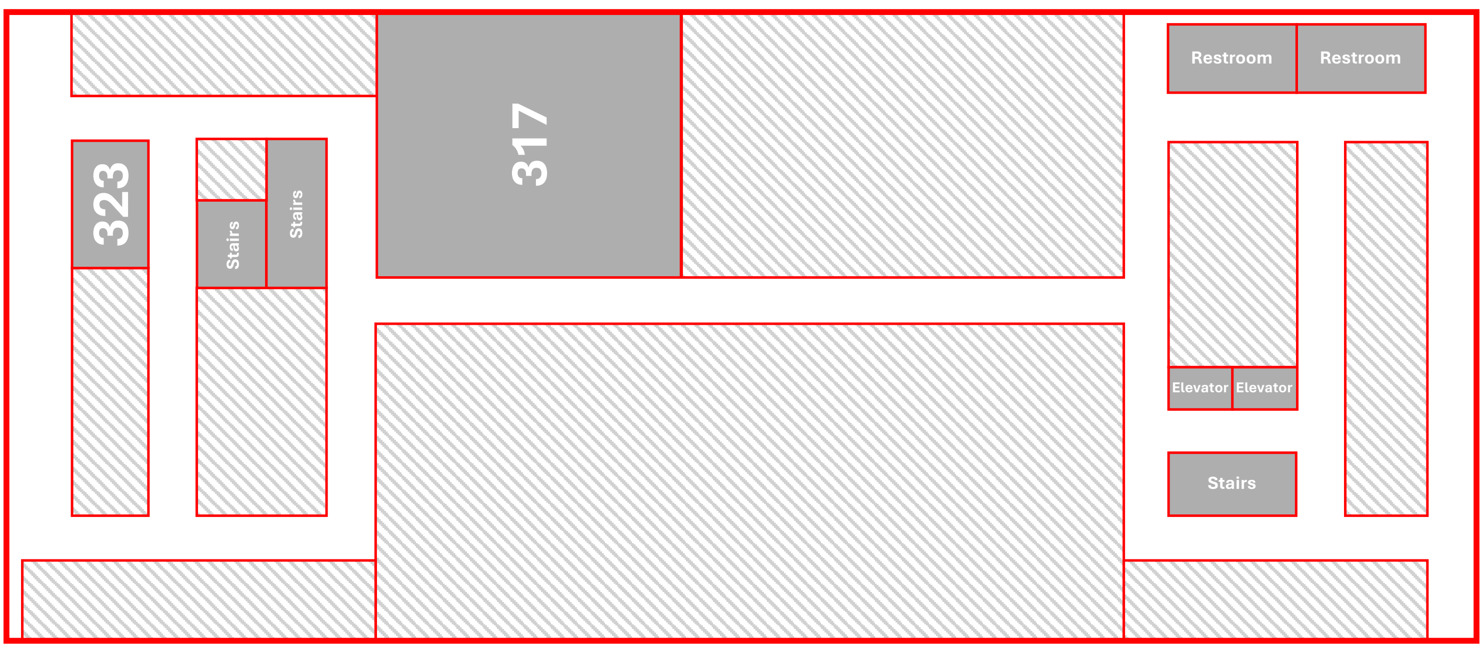
Model Coupling: SysML Extension for Physical Interaction and Signal Flow Simulation and Bidirectional Flow for Convective Transport Phenomena

Marcus Richardson, Charles Manion, Conrad Bock, Raphael Barbau

2ND FLOOR



3RD FLOOR



KEYNOTE SPEAKERS

SWAMINATHAN GOPALSWAMY

Research Professor, Director
Connected Autonomous Safe Technologies (CAST) Lab
Department of Mechanical Engineering, Texas A&M

BIO

Swami Gopalswamy is a Research Professor in the department of mechanical engineering at Texas A&M University, and the director of the Connected Autonomous Safe (and Sustainable) Technologies (CAST) Lab. His research at A&M is focused on control-enabled technologies that can lead to safer and more sustainable transportation solutions. The research at CAST spans development of fuel-efficient powertrains to new vehicle platooning concepts to techno-business paradigms such as “Infrastructure Enabled Autonomy”. He is also working on developing algorithms and software to enable coordinated movement of a fleet of heterogeneous air and ground vehicles autonomously, on off-road terrains. He has introduced Modelica as part of classes that he has taught at Texas A&M.

Previously, Dr. Gopalswamy was the CEO of Emmeskay, Inc., a company that provided modeling, simulation and other advanced technology solutions to the automotive industry. As part of Emmeskay, Dr. Gopalswamy and his colleagues were engaged in advanced modeling and control projects based on Modelica. Subsequently, he was LMS-VP at LMS International and Siemens PL, responsible for managing a global MBSE engineering services team, as also leading the development of Control-design software products. Prior to Emmeskay, Dr. Gopalswamy was a Staff Research Engineer at General Motors R&D Center.

At GM, he was engaged in solving powertrain control challenges (such as smooth clutch-to-clutch shifting) and developing powertrain concepts (such as magnetorheological fluid devices and hybrid electric powertrains).

He holds a doctorate and master’s degree in controls from the department of mechanical engineering at the University of California, Berkeley. He has a bachelor’s degree in Mechanical Engineering from the Indian Institute of Technology, Madras.

ABSTRACT

Modeling, Simulation, and Autonomous Vehicles: Challenges and Opportunities

Modeling is abstraction of reality. As an engineering practice and skill set, modeling has evolved and been evolving over the decades aligned with two fundamental priorities – form and function. Geometric modeling to capture form has made tremendous progress, and spawned form-driven functional (primarily structural) modeling through finite element decompositions and analysis. However, the interest of the Modelica community is on functional modeling that abstracts away form and focuses on dynamic behavior of systems.

I will discuss some of my experiences in functional modeling, along with the evolution in techniques over the decades. This experience spans aero and automotive systems. The growing maturity of the field is observed in the distillation and separation of critical techniques to enable specialization and cross-leverage of expertise. The explosive growth of software content in functionality over the last decades has been a catalyst for the use of modeling for algorithm development and verification and validation of embedded software.

With the advent of machine learning, artificial intelligence, and growth of autonomous driving systems, new challenges and opportunities have emerged for modeling to be useful. There is morphing of the fundamental priorities between form and function, as photorealistic rendering of environment becomes integral to functional modeling driven by the presence of sensors such as cameras and LIDARs that observe the environment and influence dynamic behavior. The sheer growth in complexity and scale of these systems forces the exploration of distributed computations and simulations, bringing with it new questions to be answered. Uncertainty modeling and stochasticity are part and parcel of learning systems, providing yet another avenue for evolution of modeling.

Finally, continued evolution of abstraction leads to the next layer, where machines are interacting with humans. I will finish with some thoughts on the opportunities for modeling in this context.

CLAS A. JACOBSON

Senior Fellow, Systems Engineering
Carrier Global Corporation

BIO

Clas Jacobson is a Carrier Senior Fellow with over 25 years experience in Systems Engineering and Controls.

Jacobson has focused his efforts on "Model Based Development" and has contributed to several areas to develop and deploy computational methods and tools for the effective use of model based development across Carrier.

Jacobson served as Chief Scientist for the United Technologies Systems & Controls Engineering (UTSCE) organization across United Technologies Corporation and, before that, in several UTRC management and technical positions. In his Chief Scientist position, he led the creation of the UTSCE organization with a mission of driving product and product development transformation enabled by systems and controls engineering technologies.

Jacobson was a (tenured) Associate Professor at Northeastern University before joining Carrier.

ABSTRACT

Energy Urgency, Computation and Role of "Systems" Methods & Tools

Today, energy considerations are critical and policy issues matter more than in the recent past, so that there is a newfound urgency to address cost, climate and security. These kinds of decisions require very large capital investments; how do we address the risks involved and the choices that are to be made? Several things are needed that are described in this talk. First, well-crafted design flows are needed to determine how overall capabilities will be considered, designed, implemented, and maintained. Second, it is essential that we understand what we can compute today and what we cannot compute, as well as the reliability of these computations and their accessibility to a wide set of groups. A few examples of energy districts and data centers will be used to illuminate what we can do and what we cannot. What should the audience thus take away from this presentation? Computing is much more than simulation. Computation --- in reliable and trusted ways - is a key element to decision making today, but not all the pieces are in place. In particular, the workforce in "computational engineering" and their training in academia needs to be used and designed to scale.

ABSTRACTS

Model-Based Design and Characterization of an Actuator with Low-Boiling Liquid

Christoph Steinmann | christoph.steinmann@tu-dresden.de
Johannes Herold | johannes.herold2@tu-dresden.de
Jens Schirmer | jens.schirmer@tu-dresden.de

Institute of Electromechanical and Electronic Design, TUD Dresden University of Technology, Germany

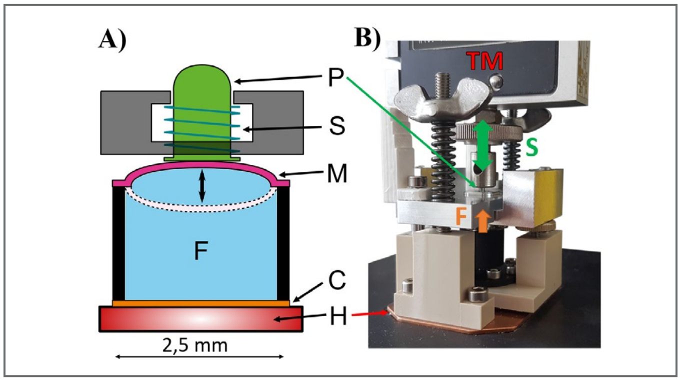


Figure 1.
A) Components of actuator prototype from bottom to top: heatplate H, copper foil C, fluid F, membrane/foil M, spring S, pin P
B) Experiment with tensile testing machine TM, stroke S and force F

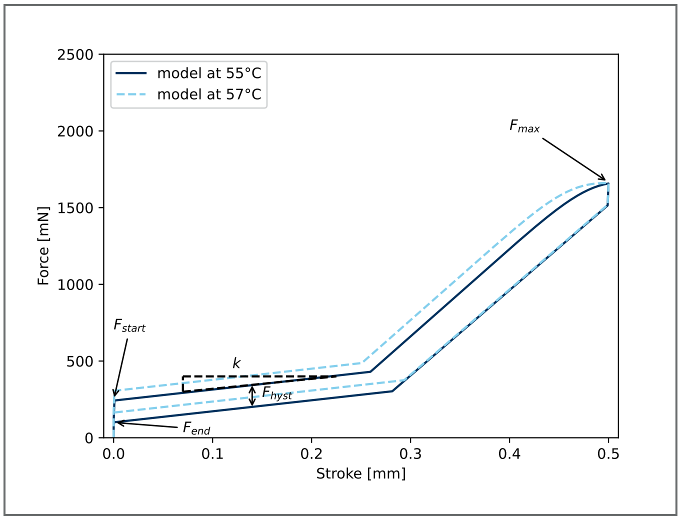


Figure 2.
Simulation results with characteristic points on the actuator curve

Visually impaired people rely on special tactile displays for access to graphic representations in digital form. For dot based graphical output the most common method is to feel mechanically elevated surfaces. This function can be implemented with a variety of physical principles like electric motors, shape memory alloy, light, pneumatic or piezoelectric actuators. Unfortunately the available devices are very large and expensive. A simple and costeffective alternative is therefore desirable. This paper evaluates the concept of a lifting phase change actuator (PCA) based on a fluid with a low boiling point for this purpose.

A concept and the the functional prototype of the PCA is shown in Figure 1. Similar concepts have often only been described in the literature with very simple assumptions and mainly characterized by practical tests. The structure of the actuator is intentionally kept simple in order to facilitate the construction of a model using Modelica (Mattsson and Elmqvist 1997). The thermodynamic reference model REFPROP (Lemmon et al. 2018) is used to describe the complex behavior of the phase change during operation.

For evaluation, the PCA was compressed with a tensile testing machine and the actuator force was measured. The simulation of this process and the resulting forcedisplacement characteristic curve is shown in Figure 2.

With the knowledge about the structure and function of the actuator and its individual components from the model, meaningful characteristic properties could be defined on the simulated and measured curves, which enable a comparison between model and measurement.

Overall, it was shown that the system simulation approach can be used in combination with thermodynamic reference models to simulate PCAs for tactile applications. The structure is intuitive due to the existing objectoriented libraries and can be easily adapted to further work. They therefore form a useful basis for the product development processes when evaluating solution concepts.

Keywords: haptic display, multi-domain model, liquid-togas phase change actuator, low-boiling liquid

REFERENCES

Lemmon, Eric W. et al. (2018). “NIST standard reference database 23: reference fluid thermodynamic and transport properties-REFPROP, Version 10.0, National Institute of Standards and Technology”. In: *Standard Reference Data Program, Gaithersburg.*

Mattsson, Sven Erik and Hilding Elmqvist (1997). “Modelica - An International Effort to Design the Next Generation Modeling Language”. In: *IFAC Proceedings Volumes* 30.4, pp. 151–155. DOI: https://doi.org/10.1016/S1474-6670(17)43628-7.

Dynamic Modeling Methodology for Near Isothermal Compressor

Haopeng Liu | hliu1220@umd.edu
Vikrant Aute | vikrant@umd.edu
Yunho Hwang | yhhwang@umd.edu
Cheng-Yi Lee | cylee@umd.edu
Jan Muehlbauer | muehlie@umd.edu
Lei Gao | leigao@umd.edu

Center for Environmental Energy Engineering, Department of Mechanical Engineering, University of Maryland, College Park, USA

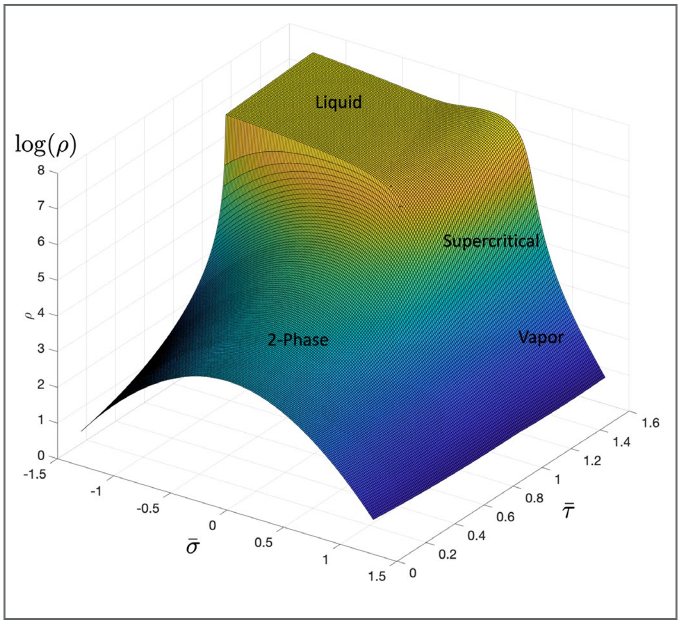
Compressors are the vital component of the vapor compression systems and account for the majority of energy consumption. Developing appropriate controllers or optimizing compressor design can significantly reduce the carbon emissions. The isothermal compressor combines the compressor chamber and gas cooler, using the liquid piston to compress the working fluid for near-isothermal compression. This methodology can reach up to 30% energy saving compared to the traditional isentropic compression work. This paper leverages the CEEE Modelica Library (CML) to demonstrate a detailed isothermal compressor model that captures the near-isothermal compression process of transcritical carbon dioxide (CO_2) cycle. The model uses the real experimental data as the boundary conditions, and the relevant component-level experimental validation was carried out by using a prototype with 1-ton nominal capacity. The results proved the accuracy of the dynamic model (7.5% relative error for chamber pressure and 0.74 K deviation for chamber temperature), and provide a guideline for designing the isothermal compressor chamber. Finally, the modeling for the isothermal compression cycle is ongoing and the filed is still in its infancy.

Keywords: Isothermal Compressor, Transcritical CO_2 Cycle, Dynamic Modeling

Fluid Property Functions in Polar and Parabolic Coordinates

Scott A. Bortoff | bortoff@merl.com
Christopher R. Laughman | laughman@merl.com
Vedang Deshpande | deshpande@merl.com
Hongtao Qiao | qiao@merl.com

Mitsubishi Electric Research Laboratories, Cambridge, MA, USA



Fluid property functions relate fluid property variables such as temperature, pressure, density, etc., to one another. For a fluid of fixed composition in thermodynamic equilibrium, all fluid property variables can be calculated as a function of a mixture variable and a second variable. Two representations of fluid property functions are presented. Both are well-defined for regions of practical interest, including the two-phase, vapor, liquid, and super-critical regions. For each representation, coordinates are defined to be aligned with the saturation curve, so that the discontinuity in derivative across the saturation curve is represented in terms of only one of the coordinates, which is defined to be constant along the saturation curve. In both representations, the critical point is no different from any other on the saturation curve, so that supercritical problems are no different than purely subcritical ones.

First, a normalized polar coordinate system is used to define fluid property functions. In these coordinates, the interior of the unit disk represents the two-phase region, and the liquid, supercritical and vapor regions are represented in the exterior of the unit disk. The saturation curve is an arc of the unit circle. Second, a normalized parabolic coordinate system is used. In normalized parabolic coordinates, the saturation curve is represented as a unit parabola in one of the two coordinates, which is naturally similar in shape to the saturation curve expressed in conventional (h; P) variables. In both realizations, fluid property functions are represented as B-spline functions, arranged such that the transition across the saturation curve is C_0 but not C_1. B-spline coefficients are computed off-line by solving a constrained least squares problem using data generated by a reference calculator such as REFPROP. The resulting fluid property functions are computationally efficient and well-conditioned, but some of the peculiarities of parabolic coordinates require additional attention. Both are realized as a set of C language functions, with interface to Modelica though the external function interface.

Objectively Defined Intended Uses, a Prerequisite to Efficient MBSE

Erik Rosenlund[1,2] | erik.rosenlund@saabgroup.com
Robert Hällqvist[1,2] | robert.hallqvist@saabgroup.com
Robert Braun[2] | robert.braun@liu.se
Petter Krus[2] | petter.krus@liu.se

[1]Saab Aeronautics, Linköping, Sweden
[2]Fluid and Mechatronic Systems, Linköping University, Sweden

This paper addresses the growing need for standardized and objective methods to define the intended uses of models in Model-Based Systems Engineering (MBSE), especially within the context of Large-Scale Simulators (LSS). The challenges associated with verifying model credibility, ensuring reuse, and achieving simulation credibility are explored. The authors propose a methodology that emphasizes the importance of machine-interoperable traceability of model verification data. The method enables automated assessments of model relevance and evaluates the interaction of combinations of models. The paper showcases a proof-of-concept testbed designed to verify black-box models against specified requirements, demonstrating how legacy models often developed under traditional document-centric paradigms can be adapted for modern MBSE practices.

A key contribution of the paper is the introduction of a machine-readable format for encapsulating model requirement verification results. This format leverages XML-based structures, aligning with standards such as the System Structure and Parameterization - Traceability (SSP Traceability) and the Simulation Resource Meta Data (SRMD) formats, to enhance interoperability and support automated reasoning about model applicability and validity. The authors discuss the use of Operational Domains (ODs) to define the feasible input space for models and argue for the necessity of transitioning from implicit to explicit model requirements to ensure traceability and support robust model reuse.

The proposed framework addresses the limitations of current practices by enabling more concrete assessments of model validity across various scenarios and life-cycle phases. It integrates Verification & Validation (V&V) activities into a cohesive process that supports continuous and automated credibility assessments. The framework provides flexibility by supporting basic approaches like grid or random search for model exploration while accommodating custom implementations of advanced search patterns.

The authors present an application example involving Environmental Control System (ECS), heat source and heat-sink models to illustrate the proposed framework's effectiveness. The results show that the use of convex hulls to represent ODs provides a more nuanced depiction of model capabilities than traditional hypercube representations. Additionally, the study demonstrates how model aggregation can be effectively managed using the proposed SRMD extensions, enabling the creation of aggregated ODs that support system-level verification.

In conclusion, the paper highlights the importance of clearly defined and machine-interpretable intended uses for models in MBSE. The proposed methodology and the supporting XML format provide a scalable solution to enhance model reuse, streamline V&V processes, and improve overall simulation credibility. Future research directions include refining the proposed methods for OD generation, exploring more advanced model exploration algorithms, and validating the approach across a broader range of MBSE applications. This work advances the state-of-the-art in MBSE by providing a structured approach to model verification, enabling more reliable and efficient use of simulations in engineering decisionmaking.

Keywords: Verification and Validation, Operational Domain, Large-Scale Simulators (LSS), Machine-Interoperable Traceability, Model Reuse, Model Exploration, Simulation Credibility, FMI, SSP, SSP Traceability

Modelica Supported Automated Design

Ion Matei | ion.matei@sri.com
Maksym Zhenirovskyy | aksym.zhenirovskyy@sri.com
John Maxwell | john.maxwell@sri.com
Saman Mostafavi | saman.mostafavi@sri.com

SRI, USA

We propose a component-based, automated, bottom-up method for system design using models expressed in the Modelica language. This language is used to describe both the basic components and the generated design solutions, allowing subject matter experts to interpret and evaluate the results. Our bottom-up approach relies on a meta-topology that is iteratively refined through optimization. Each topology link is represented by a universal component, which is defined using atomic elements (e.g., resistors, capacitors in the electrical domain) or more complex canonical components with a well-defined function (e.g., operational amplifier-based inverters). The activation of these links is controlled by discrete switches.

The design challenge lies in identifying the correct switch assignments and component parameter values to meet the specified requirements, which can involve the time evolution of certain quantities of interest or the characteristics of a transfer function, as in filter design. The optimization process also incorporates dynamic constraints and parameter bounds (e.g., resistances must be non-negative). To manage the combinatorial complexity of the resulting mixed-integer optimization problem, we convert the discrete switches into physically realizable continuous switches. This allows us to reformulate the problem as a parameter optimization task, where both component and switch parameters are learned. We encourage sparsity in the topology by applying L1 regularization to the continuous switch parameters. Furthermore, we reduce the time complexity of the optimization by reconstructing intermediate design models when components become redundant, and by simplifying topologies through the elimination of disconnected or collapsed components. Additionally, we employ parallel execution of multiple optimization runs to generate a diverse set of design solutions, addressing the non-uniqueness of the optimization outcome.

To demonstrate our approach, we apply it to the design of several electrical circuits. In the first example, we rediscover the Cauer analog filter using passive components. In the second example, we present a design for the Cauer filter implemented with operational amplifiers. For such designs, universal components are defined with respect to canonical configurations of operational amplifiers (e.g., first- and second-order low- and high-pass filters). In the third example, we showcase a design for a voltage level shifter based on operational amplifiers. Although our results are focused on the electrical domain, this approach can be generalized to other physical domains (e.g., mechanical) by defining equivalent universal components.

Proposal for A Context-oriented Modelica Contributing to Variable Structure Systems

Zizhe Wang[1,2*] | zizhe.wang@tu-dresden.de
Manuel Krombholz[2*] | manuel.krombholz@tu-dresden.de
Uwe Assmann[2] | uwe.assmann@tu-dresden.de
John Tinnerholm[3] | john.tinnerholm@liu.se
Christian Gutsche[1,2] | christian.gutsche@tu-dresden.de
Volodymyr Prokopets[2] | volodymyr.prokopets@tu-dresden.de
Sebastian Götz[2] | sebastian.goetz1@tu-dresden.de

*Co-first authors

[1]Boysen-TU Dresden-Research Training Group, Dresden, Germany
[2]Software Technology Group, Technische Universität Dresden, Germany
[3]Department of Computer and Information Science, Linköping University, Sweden

Context-aware systems are widespread in our daily lives, but modeling languages that address the notion of context are rare. Variable structure systems (VSS) allow for structural and behavioral changes in physical models at runtime (while the simulation is running) based on different situations. It is desirable to explicitly describe under which contextual situation a specific variant of the simulation model should be used and how to implement the switching between these variants at runtime. In this case, contexts could be used to control the variability of context-aware systems. Equation-based modeling languages are suitable for modeling complex multi-domain, multi-physical systems, and among them, Modelica is the state-of-the-art. Unfortunately, the capabilities for VSS in Modelica are strongly limited. As a result, several frameworks have been proposed to address this problem by supporting different VSS types. However, it remains unclear which framework contributes to which VSS type. Furthermore, approaches have been developed to support VSS, but none can explicitly describe contexts and their transitions. In this work, we first introduce VSS and its different types. Then, we provide an overview of which framework targets which VSS type. Finally, we propose a new language extension based on Modelica, ContextModelica, that provides semantics for the direct context definition, enabling the use of context to control and manage variability.

Keywords: modeling and simulation, Modelica, variable structure systems, context, context-oriented programming, ContextModelica

Building Power System Models for Stability and Control Design Analysis using Modelica and the OpenIPSL

Srijita Bhattacharjee[1] | bhatts10@rpi.edu

Luigi Vanfretti[1] | vanfrl@rpi.edu

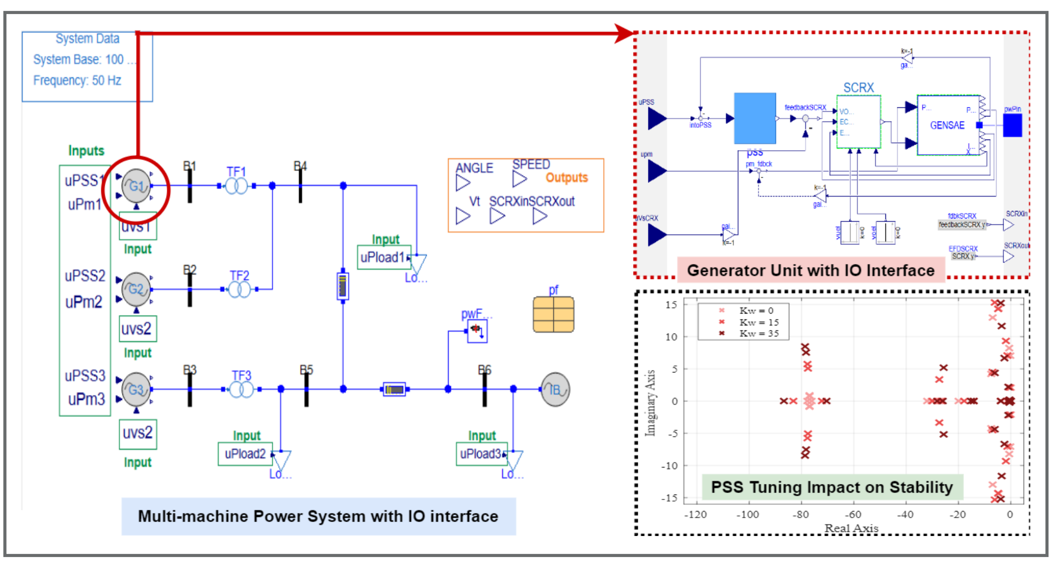
Fernando Fachini[2]
fernando.fachini@dominionenergy.com

[1]Department of Electrical, Computer, and Systems Engineering, Rensselaer Polytechnic Institute, NY, USA
[2]Electric Transmission Strategic Initiatives, Dominion Energy, VA, USA

Ensuring the stability of complex power system models is a critical challenge in electrical power engineering, and the tuning of Power System Stabilizers (PSS) plays a pivotal role in this endeavor. Modelica, an open-access modeling language, emerges as a powerful tool for this purpose, due to its distinctive features that facilitate efficient power system modeling. This paper explores the capabilities of Modelica using the OpenIPSL library to create models to analyze control system designs developed for a multi-machine power system model. The paper highlights the advantages of using object-oriented modeling to construct a multi-machine power system model. The model is structured into several sub-packages, such as GenerationUnits, Networks, and Systems. By leveraging Modelica's object-oriented modeling features, the approach allows for accurate initialization and enhances the adaptability of the overall model.

This work also highlights how the linearization capabilities of Modelica provide a significant advantage over domain-specific power system tools, enabling effective model implementation and control system design analysis. The paper also demonstrates the model being rendered into a single-input-single-output (SISO) block, providing increased flexibility for testing different input scenarios. The time-domain simulation illustrates the effectiveness of this approach. Given the complexity of power systems and the critical role of stability and dynamic behavior, the results reflect the importance of careful control design analysis to maintain system robustness. The study demonstrates that PSS tuning significantly enhances system stability and damping. These results validate the effectiveness of using the Modelica-based approach for building power system models, specifically for stability and control design analysis, by accurately simulating and analyzing the dynamic response of complex systems to various disturbances.

Figure 1.
Overview of the Multi-Machine Power System Model in Modelica using OpenIPSL for Control System Design Implementation and Stability Analysis.



Integrating the IEEE/CIGRE DLL Modeling Standard to Use "Real Code" Models for Power System Analysis in Modelica Tools

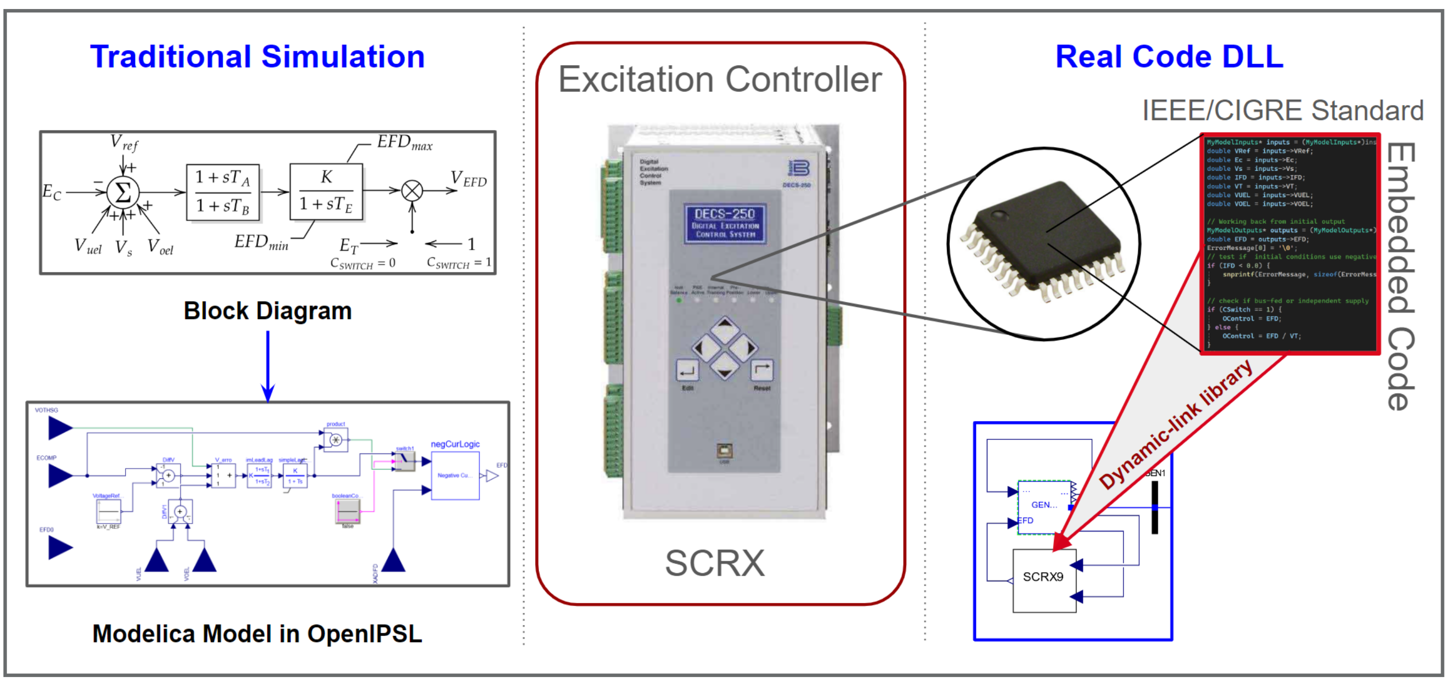
Hao Chang | changh7@rpi.edu

Luigi Vanfretti | luigi.vanfretti@gmail.com

Electrical, Computer and Systems Engineering Department, Rensselaer Polytechnic Institute, Troy, NY, USA

Vendors of power system simulation tools are investigating the incorporation of actual controller code into specialized simulation environments. To facilitate this, IEEE and CIGRE have collaboratively created the IEEE/CIGRE DLL Modeling Standard. However, adoption by simulation tool providers has been minimal. The limited adoption is because 'real code' models per the IEEE/CIGRE DLL Modeling Standard must be provided as DLLs by equipment vendors. Thus, to support the standard, tools need to support a standardspecific interface and provide additional functions to execute the models.

This paper presents a method for integrating 'real controller code' models (RCMs) built according to the IEEE/CIGRE DLL Modeling Standard into Modelica-based tools. This is achieved by linking precompiled C code to Modelica models and using components from the OpenIPSL library. The approach is demonstrated with an RCM of a simplified silicon-controlled rectifier excitation system (SCRX). The paper discusses the details of the implementation, challenges, and solutions. The findings show that this method allows RCMs to be used in Modelica tools for power system simulations, providing a valuable alternative to specialized simulation tools.



Decentralised Hydrogen Fuelled Gas Engine CHP Units: A Feasibility Study with Modelica

Florian Andreas Beerlage | florian.beerlage@h-ka.de
Naqib Salim | muhamad_naqib.md_salim@h-ka.de
Maurice Kettner | maurice.kettner@h-ka.de

Institute of Refrigeration, Air-Conditioning and Environmental Engineering, Karlsruhe University of Applied Sciences, Germany

The use of hydrogen gas as an alternative fuel to power energy systems has been a topic of research over the last few decades and is currently gaining importance, even more due to current circumstances related to decarbonise energy supply. One focus of research is the use of hydrogen gas in combined heat and power gas engines, as this type of energy conversion is known for its high efficiency. For this reason, a cross-border project between France and Germany is developing a living laboratory in the Upper Rhine region to investigate the feasibility of hydrogen gas as an alternative fuel in a holistic decentralised energy system[1]. It consists of several energy components, including a polymer electrolyte membrane electrolyser (PEMEC), gas engine combined heat and power (CHP) unit, photovoltaic (PV) panels, hydrogen storage, thermal and electrical energy storage. To enable and demonstrate multiple what-if scenarios of possible variations of the energy system, a simulation model was developed using Modelica. Users, e.g. local authorities, landlords, businessman etc., of this simulation model could utilize it as a decision support tool for designing a carbon neutral energy system for their own use. This paper describes the development of the model and its application with real measured data from municipal buildings in the city of Offenburg, Germany. The results indicate that the suitability of the model and the use of hydrogen CHPs can be beneficial for this specific use case.

Keywords: Hydrogen, HVAC, CHP, Electrolyser, Gas engine, Cogeneration

[1]For more information please visit this website: https://co2inno.com

FMI-3.0 Export for Models with Clocks in a Signal Flow Diagram Environment

Masoud Najafi | masoud@altair.com
Ramine Nikoukhah | ramin@altair.com

Altair Engineering France, France

The Functional Mock-up Interface (FMI) standard has become a widely accepted tool-independent standard for exchanging dynamic models and supporting co-simulation across different platforms. The latest FMI-3.0 version introduces new features, such as clocks and arrays, to enhance model synchronization and simulation capabilities. Altair Twin Activate (TA), a simulation environment for hybrid systems, already supports the use of continuous-time and discrete-time models using clocks and events. The handling of clocks in FMI-3.0 should be independent of the FMU implementation and should allow uniform behaviour in clock handling in tools. However, differences in how TA and FMI-3.0 handle clocks present challenges for exporting models from TA in FMI-3.0 format.

This paper focuses on how models with clocks in TA, including input periodic and triggered clocks, can be successfully exported in both FMI-2.0 and in particular FMI-3.0 standard. It addresses the semantic differences between TA and FMI-3.0 clock mechanisms, particularly concerning periodic and triggered input clocks, and presents solutions for overcoming these differences. While TA's activation signals and event handling offer flexible modeling capabilities, they differ from the clock handling in FMI-3.0, necessitating specific adaptations during export.

Key challenges include mapping TA's clock types, such as predictable events (like time-based clocks in FMI-3.0) and unpredictable events (like triggered clocks), to FMI-3.0 clocks. Additionally, the paper discusses how TA's event synchronization is managed during export, exploring issues such as simultaneous but asynchronous events and the interaction between multiple clocks. Two code generation techniques in TA, i.e., standard, and inline code-generations are explored to enable efficient FMU export, ensuring compatibility across simulation platforms via FMI-3.0 standard. At the end, the way a continuous-time model can be discretized to and exported to convert the continuous-time model to a purely clocked discrete-time model will be explained.

Event Support for Simulation and Sensitivity Analysis in CasADi for Use with Modelica and FMI

Joel Andersson[1] | joel@jaeandersson.com

James Goppert[2] | jgoppert@purdue.edu

[1]Freelance software developer and consultant (USA)

[2]School of Aeronautics and Astronautics, Purdue University (USA)

We present a generalization of the ODE/DAE sensitivity analysis support in CasADi to dynamic systems with events.

CasADi is an open-source optimization framework that can be used to efficiently solve optimization problems involving user-defined ODE/DAE models. Supported solution methods include so-called shooting methods, where solvers for initial-value problems in ODEs or DAEs are referenced inside in nonlinear programming (NLP) formulations. In order to solve such NLP formulations with gradient-based algorithms, CasADi implements a fully automatic sensitivity analysis using a variational approach. This analysis includes forward sensitivity analysis, adjoint sensitivity analysis as well as the calculation of higher-order sensitivities. The numerical solution can be performed with variable-step size, variable-order integrators such as those from the SUNDIALS suite.

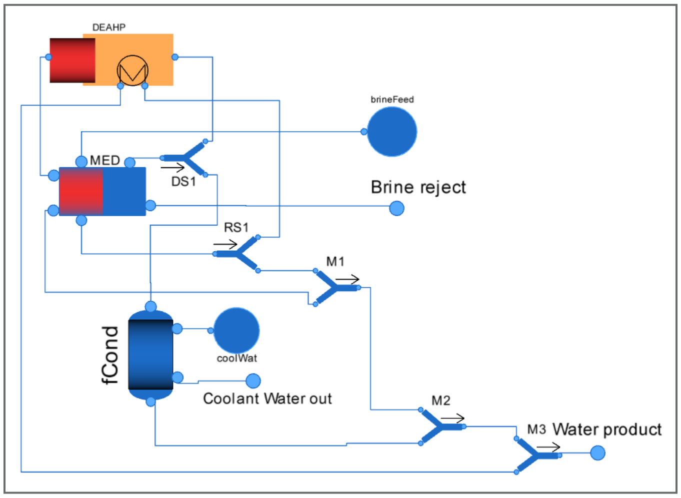
Using the presented extension, it becomes possible to formulate and solve optimization problems that include dynamic systems with events, without a priori knowledge of the number and ordering of events. Ultimately, we expect the proposed approach to be compatible with general cyber-physical models formulated in Modelica or available as modelexchange FMUs.

We demonstrate the proposed approach for three proof-of-concept examples; the classical bouncing ball written in CasADi directly, a simple hybrid DAE formulated in Modelica and imported symbolically into CasADi and finally a standard FMU generated from Modelica sources, imported via CasADi's FMI foreign function interface. In the last case, in order to be amenable to the approach, we introduce some reformulations and naming conventions to the Modelica sources, prior to FMU generation. In the examples, we show that the sensitivities calculated to high precision using the proposed approach are consistent with a cruder finite-difference approximation and provide examples on how they can be embedded into optimization formulations.

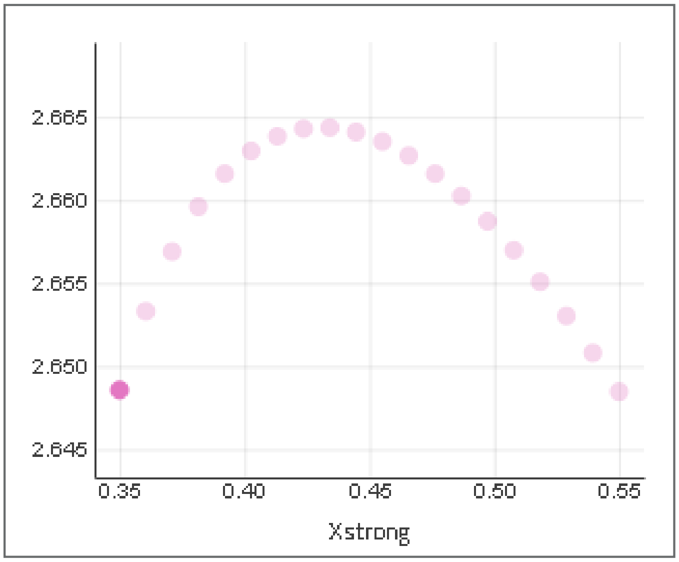
Steady-State Optimization of Modelica Models and Functional Mockup Units with Pyomo

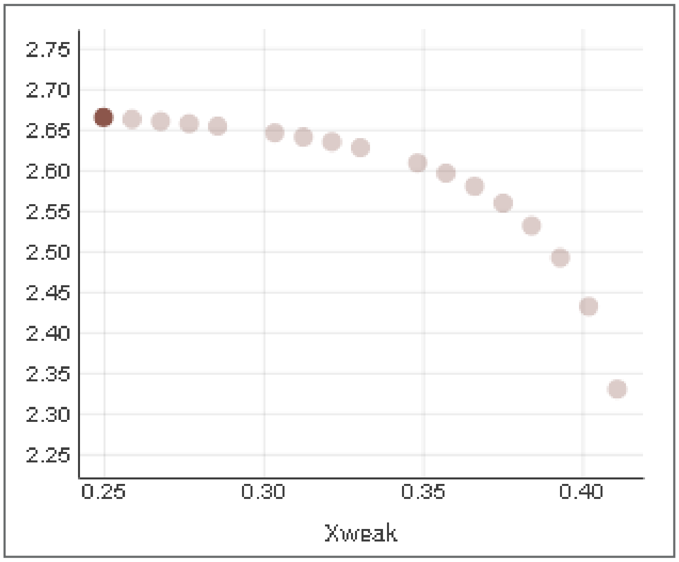
Jesse Gohl[1] | jesse.gohl@modelon.com
Hubertus Tummescheit[1] | hubertus.tummescheit@modelon.com
Robin Andersson[1] | robin.andersson@modelon.com
Matthew Stuber[2] | matthew.stuber@uconn.edu

[1]Modelon Inc, USA
[2]Dept. of Chemical & Biomolecular Engineering, University of Connecticut



This paper describes two ways on how to interface Functional Mockup Units (FMUs) and Modelica models through the Pyomo's foreign function interface with Pyomo. Pyomo is a Python-based, open-source optimization modeling language with a diverse set of optimization capabilities. Modelica has arguably much better modeling capabilities than Pyomo, but Pyomo integrates excellent optimization solvers, such as Ipopt (Wächter et al. 2006), and provides a good optimization infrastructure. The Interface has been developed in the context of a NAWI, (National Alliance Water Innovation) Hub project in collaboration with the University of Connecticut and Sandia National Labs. The optimization has been set up and tested within Modelon's Modelica platform Modelon Impact. An unpublished, detailed multi-effect desalination plant developed by Prof. Matt Stuber in the context of (Stuber et al., 2015) has been used to demonstrate the capabilities, as well as simple test models, and design models from Modelon's commercial Libraries.





Development and Validation of a Water-to-Air Heat Pump Model Using Modelica

Yuhang Zhang | yuhang.zhang@tamu.edu
Mingzhe Liu | mingzhe.liu@tamu.edu
Zhiyao Yang | z.yang@tamu.edu
Caleb Calfa | cjcalfa@tamu.edu
Zheng O'Neill | zoneill@tamu.edu

J. Mike Walker' 66 Department of Mechanical Engineering, Texas A&M University, USA

Water-to-air heat pumps are increasingly utilized in Heating, Ventilation, and Air Conditioning (HVAC) systems due to their energy efficiency, environmental friendliness, and versatility in providing both heating and cooling. However, the lack of readily available and validated Modelica models that support reversible operation, utilize compressor speed as a control variable, and accurately predict system performance has created a significant gap in the field. This paper addresses this gap by developing a variable-speed reversible water-to-air heat pump model using Modelica.

The Modelica implementation leverages and extends the capabilities of existing Direct Expansion (DX) coil models from the Modelica Buildings Library, incorporating modifications that account for compressor speed as a performance modifier. The model employs polynomial equations-based performance curves to estimate critical system-level parameters such as total capacity and Energy Input Ratio (EIR), taking heat pump operational mode, inlet temperatures, mass flow rates, and compressor speed as the inputs. The performance curves are derived from manufacturer-provided data and fitted using the generalized least squares method. They are used to represent the steady-state performance of the heat pump across various operational conditions.

Validation of the developed model is conducted using data from a real heat pump testbed located at Texas A&M University. The testbed features a 2-ton water-to-air heat pump with load emulators to replicate different testing conditions. The model's predictions of system capacity, Energy Input Ratio (EIR), and power consumption are compared against the measured values from the testbed. The results demonstrated that the model's predictions align closely with the experimental data, with error metrics (i.e. Normalized Mean Bias Error (NMBE) and Coefficient of Variation of the Root Mean Squared Error (CVRMSE)) falling within acceptable ranges. These findings validate the model's effectiveness in simulating the performance of variable-speed water-to-air heat pumps, particularly during normal continuous operation stages.

However, the model shows limitations in capturing transient behaviors such as startup and shutdown cycles, as the performance curves employed are primarily suited for steady-state conditions. This highlights the current model's applicability for scenarios where continuous operation performance is the primary concern but suggests that alternative modeling approaches may be necessary for scenarios requiring detailed analysis for the cycling periods.

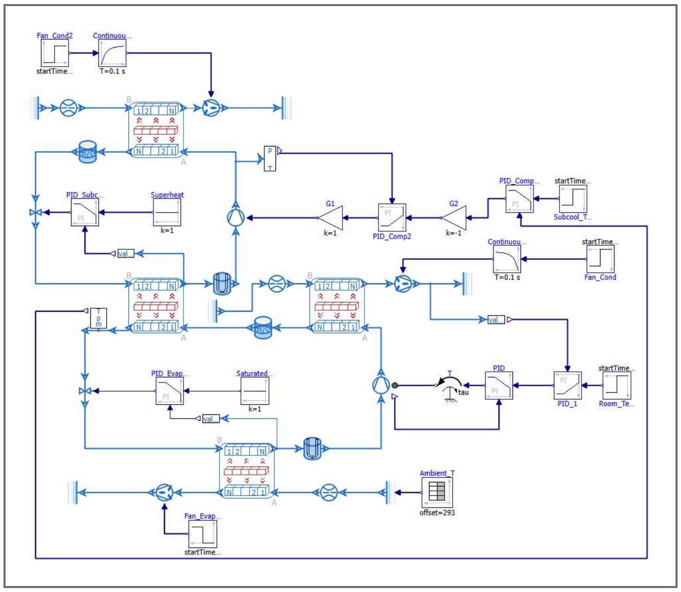
In conclusion, the developed Modelica model provides a valuable tool for simulating the performance of variablespeed reversible water-to-air heat pumps, with potential applications in advanced control strategy development and building-to-grid integration. Future work will focus on improving the model's prediction accuracy for sensible heat ratio (SHR) and extending its application to broader scenarios, including district pump systems. The findings of this study contribute to advancing the state of modeling and simulation in HVAC systems, particularly in the context of energy-efficient and grid-responsive building technologies.

Keywords: Modelica, Water-to-air heat pump, Performance curve, Validation

Enhancing COP through Sub-Cooling Temperature Control in Dual Heat Pump Systems: A Dynamic Simulation Study using OpenModelica

Zahra Hajabdollahi | Zahra.Hajabdollahi-Ouderji@liverpool.ac.uk
Zhibin Yu | Zhibin.Yu@liverpool.ac.uk

Mechanical and Aerospace Engineering, University of Liverpool, United Kingdom



This study enhances dual heat pump systems by integrating a sub-cooler after the condenser to recover heat, which is then used to operate a secondary heat pump. The aim of this paper is to develop a unified standard control system focused on enhancing energy efficiency and balancing the net load demand. The system uses R1234yf refrigerant, with a focus on precisely controlling room temperature via the condenser external loop and subcooling temperature to achieve optimal Coefficient of Performance (COP). Dynamic simulations in OpenModelica, utilizing Modelica and Thermofluid Stream libraries, facilitated the examination of the system's performance under controlled conditions. Central to this approach is the regulation of mass flow rates in the external loops of the condensers and evaporators to adjust room and sub-cooler temperatures. The study compares the system with a standard heat pump, demonstrating the significant benefits of strategic heat recovery and temperature management. Moreover, the impact of variations in the heat transfer area on system stability and performance is explored in the optimum subcooling temperature.

Keywords: heat pump systems, subcooling temperature control, heat recovery, dynamic simulation, OpenModelica, thermal management

A Modelica Implementation of an Organic Rankine Cycle

Hongxiang Fu | hcasperfu@lbl.gov
Ettore Zanetti | ezanetti@lbl.gov
Jianjun Hu | jianjunhu@lbl.gov
David Blum | dhblum@lbl.gov
Michael Wetter | mwetter@lbl.gov

Building Technology and Urban Systems Division, Lawrence Berkeley National Laboratory, USA

In this paper, we report a Modelica implementation of an organic Rankine cycle (ORC) integrated into an energy system. ORC systems generate power from low-grade heat sources, such as geothermal sources and industrial waste heat. It is particularly interesting to building and district energy system applications, because in these areas both the electric power generated by the expander and the heat rejected from the condenser can be used.

Selecting a working fluid that matches the temperature of the heat source is a key step in its system design. However, developing robust and computationally efficient medium models for a wide range of candidate working fluids, accommodating heating sources ranging from geothermal sources at 80°C to biomass sources at 500°C, is a time-consuming and complex task. We circumvent this challenge by implementing a subcritical ORC model in Modelica that uses working fluid data records and interpolation schemes in lieu of thermodynamic medium evaluation for energy recovery estimation. By doing so, we avoid dependency on external software which improves model usability and compatibility. Furthermore, adding more media data records to the package is easy for users, allowing consideration of a broad pool of candidate working fluids. We selected CoolProp as the source of thermodynamic fluid properties but it is important to note that any software that provides thermodynamic fluid property data can be used to generate the data records. The model assumes a steady-state working fluid cycle, whereas the hot and cold fluid streams can be configured to be dynamic.

Figure 1 shows how the ORC component model can be used in a district heating system. Our model fills the gap of general-use, open-source ORC model in Modelica with both a working fluid model that is ready to use or easy to add, and the ability to be integrated into a larger energy system model. It can be used to obtain energy recovery estimation for system-level design and analysis.

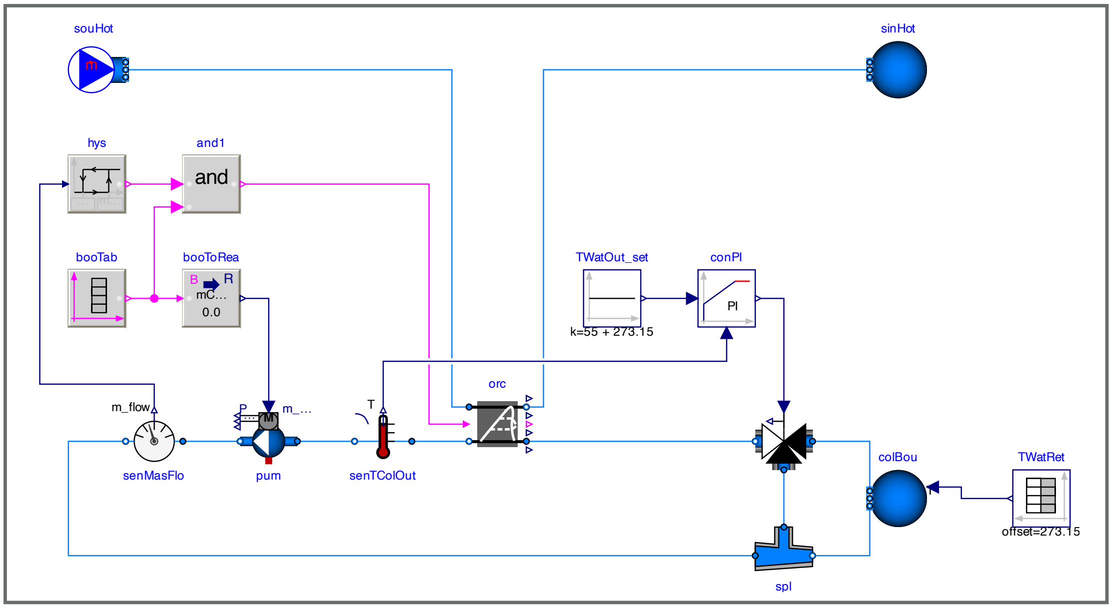


Figure 1.
Modelica graphics of the example model where the ORC component is integrated in a district heating system.

Advancements in Building-to-Grid Interactions: Thermo-Electric Coupling Models of Motor-driven Devices

Viswanathan Ganesh | viswanathan.ganesh@psu.edu
Zhanwei He | zuh45@psu.edu
Wangda Zuo | wangda.zuo@psu.edu

Penn State University, USA

Building-to-grid (B2G) integration transforms buildings into active components of the electricity grid, enhancing dynamic energy management and optimizing usage to reduce operational costs and carbon emissions. However, existing modeling tools for building and power systems often overlook or oversimplify the interactions between power system dynamics and building dynamics. This paper introduces Modelica-based thermo-electric coupling models for motor-driven devices in buildings, such as pumps and heat pumps. The developed models assess transient oscillations and negative active power in these devices within B2G systems. We compare the proposed models with a base model from the Modelica Building Library that uses a radiator and heat pump to maintain room temperature. The simulation results demonstrate that the motor-driven models effectively capture transient oscillations in current and power when the systems are activated and deactivated. Additionally, the occurrence of negative power when systems turn off is a critical factor in enhancing B2G system stability and energy efficiency. These findings underscore the model's ability to improve grid support, advancing energy management practices in B2G applications.

Modelica as Model Aggregator for Holistic Architecture Validation of Electric Vehicles

Marcel Gottschall[1] | marcel.gottschall@esi-group.com
Torsten Blochwitz[1] | torsten.blochwitz@esi-group.com
Andreas Abel[1] | andreas.abel@esi-group.com
Alex Magdanz[2] | alex@xpincorporated.com

[1]ESI Germany GmbH, Germany
[2]XPI Xcelerated Prototyping Inc., Canada

Automotive OEMs and suppliers are facing recent challenges in the development process, induced by ever shortened product cycles, further distributed development as well as increasing demands for virtual testing and certification using virtual proving grounds or digital twins.

Systems engineers describe the principal system architecture and its requirements to be fulfilled in early development stages with abstracted SysML models. Despite rare cases, these logical or functional model aspects are lacking real representations of the physical behavior of the system. On the other hand, those are often created in later design stages by verification and design engineers for detailed analysis of the system use cases. The Modelica modeling language is a well-established model description method, in particular for such analysis of the dynamic, non-linear behavior of multi-physical systems. Due to limited simulation capabilities in architecting tools, there was no efficient possibility to seamlessly link more sophisticated physical models, created in different modeling platforms by distributed engineering teams involved in the design of the system. However, providing physical system models to systems engineers would enable architectural explorations and early-stage decision making by virtual testing of defined requirements.

This paper presents a real-life demonstration of a collaborative, federated, but seamlessly integrated design process for a complex cyberphysical system (electric truck), where simulation is used for early-stage performance validation and decision making. Since holistic, but abstract architecture models created in systems engineering discipline contain relevant information with respect to logical system structure, sizing and allocated requirements, the simulation domain, particularely the aspect of model creation, will benefit from a cross-domain linking of model artefacts. By aligning system interfaces across engineering domains and model abstractions, and augmenting logical architecture models with physical information, behavioral model templates for design can be generated in a smart, traceable and automated fashion. With the additional information of requirements allocated to certain architectural components in those architecture models, it is demonstrated how automated, scenario-based component and system simulation will contribute to low fidelity analysis tasks like architecture exploration in early-stage design phase, or product family configuration selection in technical sales phases like request for proposal. In a top-down approach, also high fidelity tasks in later stages like specific design optimization are demonstrated as a major beneficiary of such efficient, continuous engineering environments. The presented modular and scalable linked-data approach enables workflows and automation incorporating modeling and simulation from various engineering domains contributing to a system lifecycle.

Multiphysics Acausal Modeling and Simulation of Satellites Using Modelica Library

Salvatore Borgia | salvatore.borgia@polimi.it

Francesco Topputo | francesco.topputo@polimi.it

Department of Aerospace Science and Technology, Politecnico di Milano, Italy

The multiphysics modeling has a great importance when a complex space system (as a satellite) is considered. Indeed, it is necessary to analyse how the system's behavior is affected by the space environment or by on board failures. In this paper, the *Modelica Library* is used to hierarchically build and connect the main subsystems that can be found in a traditional satellite. Specifically, the modeling and simulation of the entire system is carried out in the *Dymola*[1] environment. Finally, the FMI is applied to simulate in Dymola some specific satellite models/logics created with higher fidelity in the Matlab/Simulink[2] domain.

Keywords: Multiphysics modeling, Space system, Modelica library, Dymola, FMI tool

[2]https://it.mathworks.com/products/matlab.html

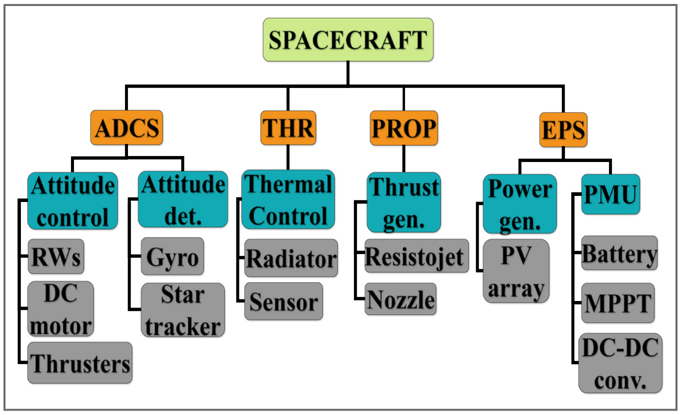


Figure 1.
Satellite breakdown structure considered for Dymola modeling.

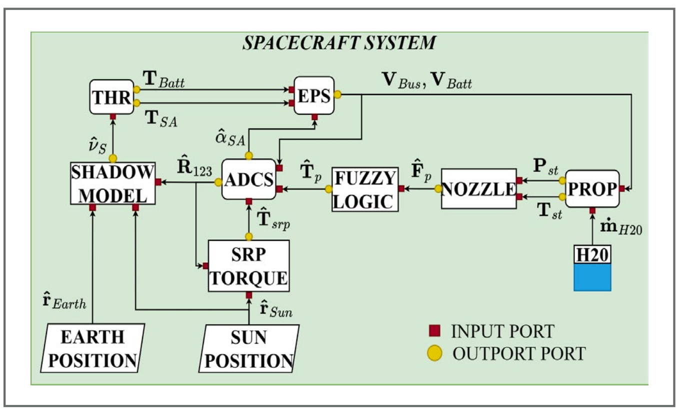


Figure 2.
Satellite physical cross-interactions.

Advanced Edge Deployment: Abstracting Cyber-Physical Models via FMU Mastery

Fanping Bu | fbu2@slb.com
Mikalai Filipau | mfilipau@slb.com
Nikolay Baklanov | nbaklanov2@slb.com

Integrated Productivity and Conveyance Center, SLB, USA

Deploying cyber-physical models at the edge or in the cloud as software components is the key step of model-based-design. Depending on run-time environment, an extensive customization often needs to be made. To streamline and facilitate the deployment of models and simulators in production, a unified framework is developed. The implementation utilizes functional mockup units (FMUs) as the executable binary for the models and JavaFMI as the simulation engine. Each model deployment is encapsulated inside a microservice with all the software dependencies, with communication realized through RabbitMQ. A generalized approach to manage the model namespace has been implemented, ensuring that the FMU executor remains agnostic to changes in both model and application, as long as the AsyncAPI specification includes a mapping of the model's input-output space to the protocol's topics. Two examples are presented to illustrate the convenience and effectiveness of the proposed framework: a winch controller at the edge for oil and gas wireline operation and a wireline logging unit simulator in the Azure DevOps pipeline for software-in-the-loop testing.

Keywords: FMU, Edge, Wireline, Oil&Gas, FMI, Cyber-Physical Systems, Deployment, Microservices

Integrating Generative Machine Learning Models and Physics-Based Models for Building Energy Simulation

Luigi Vanfretti[1] | vanfrl@rpi.edu

Christopher R. Laughman[2] | laughman@merl.com

Ankush Chakrabarty[2] | achakrabarty@merl.com

[1]ECSE Department, Rensselaer Polytechnic, Troy, NY, USA

[2]Mitsubishi Electric Research Laboratories, Cambridge, MA, USA

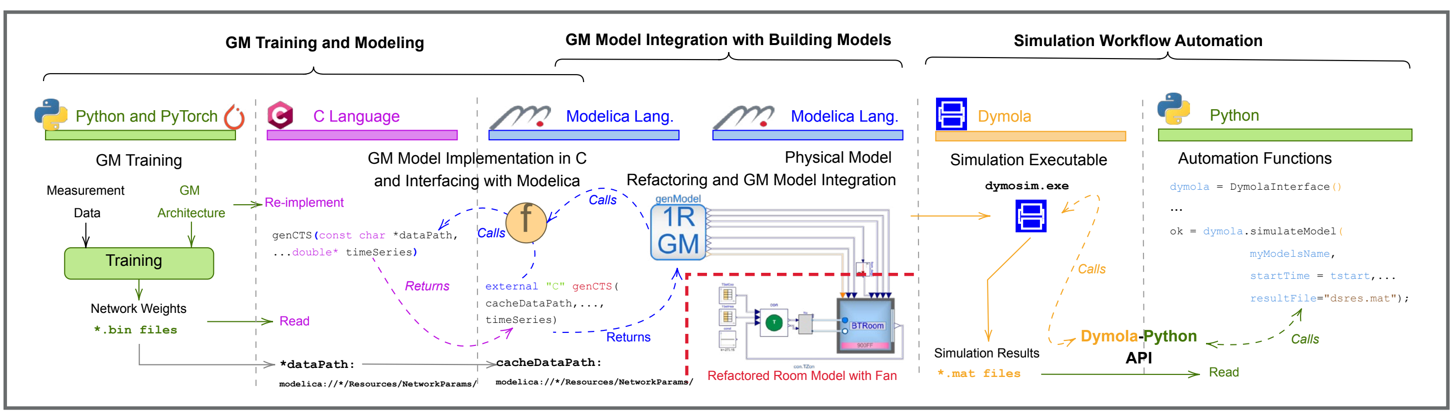
Bringing together physics-based buildings models with models that describe variables driven by human interactions has the potential to substantially improve the performance of existing buildings or to develop better informed building designs, particularly when considering heating and cooling requirements that impact HVAC systems. To explore this potential, this paper presents the requirements and a prototype implementation of the integration of machine learning generative models and physics-based building models.

An overview describing the integration of generative models for the simulation of building energy systems is shown in Figure 1. The generative models are trained to learn distributions of building input signals from data using Python and PyTorch and are interfaced with physics-based Modelica models. Meanwhile, the integration requirements developed provide background on typical needs that focus on building energy simulation portability and performance.

Once the generative models were trained, they were linked to a building model by exploiting the external function interfaces for C defined in the Modelica language specification. This enabled the reuse of Modelica building models from the Buildings library, while simultaneously leveraging real-world occupancy, power consumption, and other data for building energy simulations.

Simulation examples are presented to illustrate the benefits of the proposed integration approach and how GMs can be used for building energy performance analysis.

Figure 1.
Overview of the Desired Integration of a Generative Model with a Single-Zone Thermal Model of a Building



Pipeline-based Automated Integration and Delivery Testing of Simulation Assets with FMI/SSP in a Railway Digital Twin

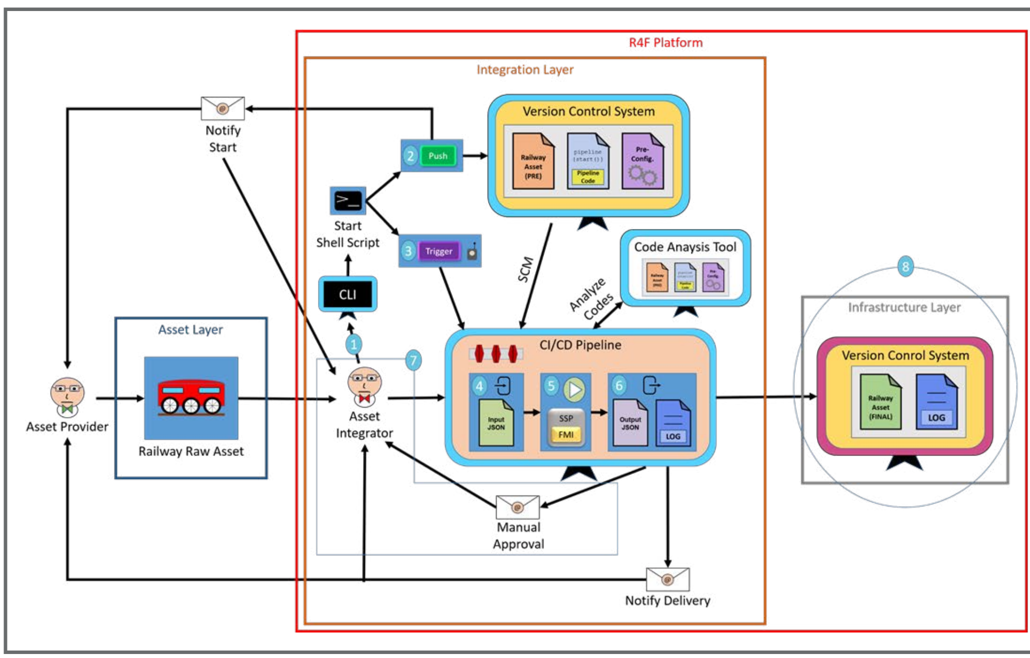
Ozan Kugu[1] | ozan.kugu@tuwien.ac.at
Shiyang Zhou[1] | shiyang.zhou@tuwien.ac.at
Stefan H. Reiterer[2] | stefan.reiterer@v2c2.at
Mario Schwaiger[2] | mario.schwaiger@v2c2.at
Lukas Wurth[1] | lukas.wurth@tuwien.ac.at
Manfred Grafinger[1] | manfred.grafinger@tuwien.ac.at

[1]Institute of Engineering Design and Product Development, TU Wien, 1060 Vienna, Austria
[2]Virtual Vehicle Research GmbH, 8010 Graz, Austria

Railway infrastructure systems have recently been enhanced through the use of the digital twin (DT) concept, enabling visualization and control in a virtual environment while effectively mitigating life cycle costs. This work provides insights into the development and operations (DevOps) of a railway DT platform and highlights the automation and management of asset integration and processing based on the FMI and SSP interface standards through the use of the Continuous Integration / Continuous Delivery pipeline technology. This offers long-term durability, pausability, remote triggering, open-source and workflow design capabilities, and connectivity to other tools such as version control systems and code analysis tools. In this research paper, we present an anti-slip co-simulation model of a railway vehicle as a use case example to demonstrate the pipeline-oriented automation and management in combination with a version control system and code analysis tool within the platform.

Keywords: CI/CD Pipeline, DevOps, FMI, SSP, Automation and Management, Asset Integration and Processing

Figure 1.
Overview of the Automation and Management Environment
SCM → Source Code Management
CLI → Command Line Interface
CI/CD → Continuous Integration / Continuous Delivery



Main Procedure Followed	
1	Start the Shell Script
2	Push Pre-Assets and Notification
3	Remotely Trigger Pipeline
4	Provide Input for Simulation
5	Start the FMI-based SSP Simulation
6	Generate Results
7	Manually Approve the Delivery
8	Deliver Asset

A Template-Based Method for Creating Modelica Simulation Models for Whole-Building Electrical Systems

Anay Waghale | anay.waghale@pnnl.gov
Karthik Devaprasad | karthikeya.devaprasad@pnnl.gov
Michael Poplawski | michael.poplawski@pnnl.gov
Tianna-Kaye Woodstock | tianna-kaye.woodstock@pnnl.gov
Shat Pratoomratana | shat.pratoomratana@pnnl.gov

Pacific Northwest National Laboratory, USA

Increasing adoption of distributed energy resources (DERs) like photovoltaic (PV), battery energy storage (BES), and electric vehicle (EV) systems in buildings can lead to a need for building-scale microgrids and dedicated microgrid controllers. In such cases, designers must make decisions about whether to convert DC power from DERs into AC before connecting them to the building AC distribution system, or to connect them to a DC bus that is distributed throughout the building. An increasing number of building systems (e.g., LED lighting) have equipment that are inherently DC loads. When AC is distributed, designers have increasing options with regards to where and how to convert AC power to DC power – at each device, or at a more centralized (e.g., electrical panel) level for all the devices in a zone or on a floor. When DC is distributed, designers need to determine the distribution voltage, and how often AC loads will use power from the DC bus as opposed to directly from the AC grid. As the energy efficiency of these different architectures is dependent on such design choices, a potential need for modeling and simulation arises to decide how to best meet project and design goals.

Previous work has demonstrated the use and validated the accuracy of Building Electrical Efficiency Analysis Model (BEEAM), a Modelica library for simulating building electrical distribution systems using harmonic power flow. Previous experiments focused on three small (4 device) lighting systems with different system architectures that were designed, modeled, and simulated, and the results were compared with laboratory measurements. While a small system can be easily modeled manually, it becomes a cumbersome task to model a whole building, with potentially hundreds or even thousands of electrical devices on each floor.

To address this challenge, an automated method for creating whole-building electrical system has been developed. This method constructs whole-building Modelica models from pre-defined templates. Templates can be selected and populated using a manually compiled input in a prescribed format, or from querying a building information model (BIM) or semantic model. There is a strong precedent for the construction of simulation models using pre-defined templates in the development of whole-building mechanical/HVAC system energy models.

Two template levels have been defined. The upper or system-level template describes the whole-building system architecture – including all AC busses, all AC/DC conversions, all pure AC loads (e.g., motors), what types of DERs are present, and instances of lower-level template. A lower-level template describes all DC loads, along with any required DC/DC conversions. All load instances are vectorized such that the model can be programmatically extended to cover varying numbers of unit loads.

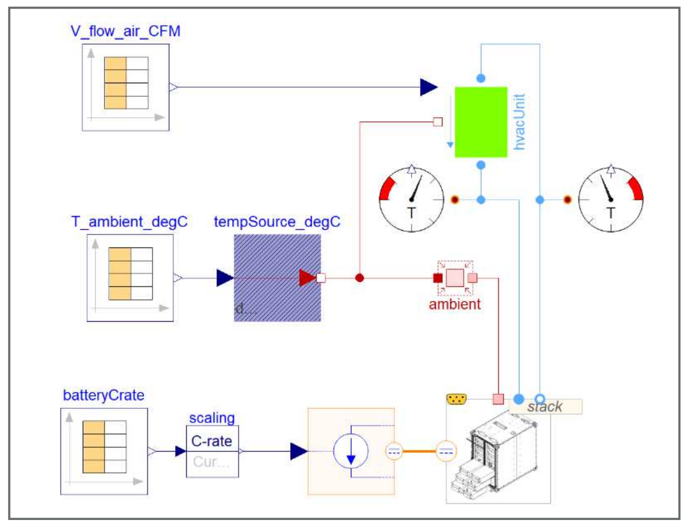
This presentation will demonstrate how this workflow was used to create whole-building electrical system models for various system architectures. Simulation results for these models will also be presented, and compared with the results obtained for models that were manually constructed. Finally, lessons learned, and next steps will be discussed.

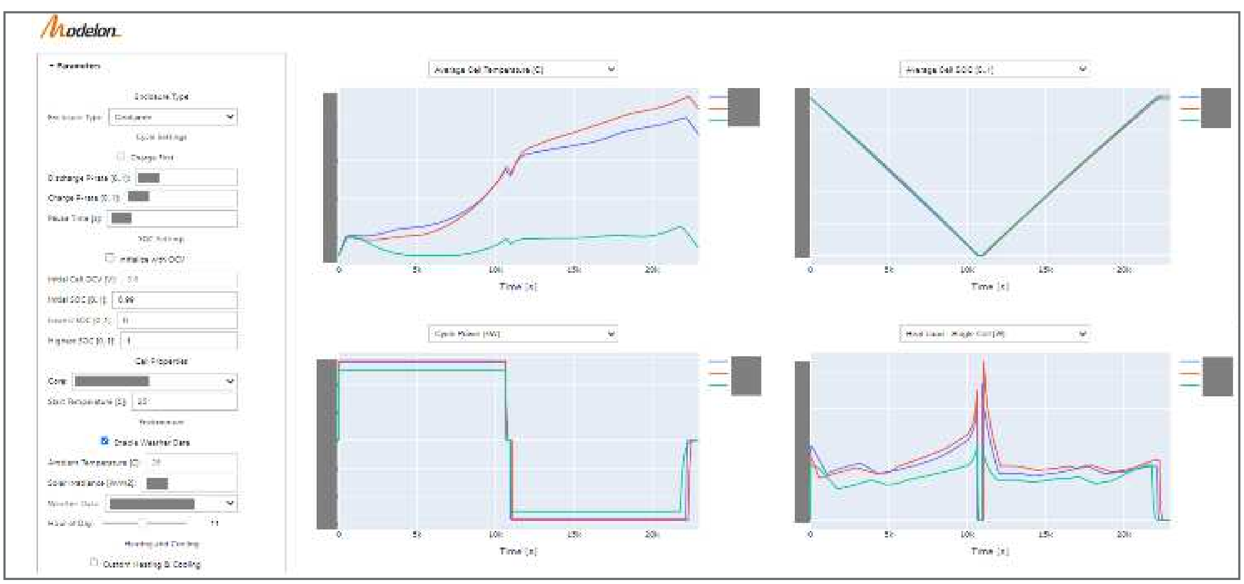
Thermal Modeling and Simulation of the Powin Energy Storage System

Cory Dinkle[1] | cory.dinkle@powin.com
Erik Durling[2] | erik.durling@modelon.com
John Batteh[3] | john.batteh@modelon.com

[1]Powin, USA
[2]Modelon AB, Sweden
[3]Modelon Inc., USA

This presentation describes the thermal modeling and simulation of the Powin Centipede Stack 750, a modular energy storage system. The focus of the modeling and simulation is on the thermal characteristics of the system including the battery, heat sink, and HVAC unit which make up the Powin S750. Following a brief introduction to the technology, an overview of the modeling of the battery to match the Powin cell is provided. Different thermal modeling approaches are discussed, and examples of the simulations with both models are included. Validation of the lumped model with lab data showed good agreement for average cell temperatures. The model is also deployed as a web application to allow evaluation of a given configured system at different loadings and site environmental conditions.





Integrated 1D-3D Thermal Design Space Toolset for Energy Management in Electric Vehicles

Amir Doroudian | adoroudi@ford.com
Ashwin Hariharan | ahariha5@ford.com
Lucas Phan | lphan6@ford.com
Rajaram Maringanti | rmaringa@ford.com

Ford Motor Company, USA

It is well known that electric vehicle range is sensitive to high-voltage battery energy used for heating, cooling, and maintaining cabin temperature. The goal of this project is to develop an analytical toolset for electric vehicle energy management by co-simulating Modelica-based 1D vehicle thermal system models with Star CCM based 3D CFD cabin models. Such an approach can help with balancing cabin/human comfort with thermal system electric energy consumption and aid with selecting hardware, control strategies and calibration that can maximize system efficiency while meeting customer expectations.

The integration of 1D and 3D models is achieved in Star CCM through co-simulation using the Functional Mockup Interface (FMI) standard. Co-simulation is an effective approach to combine 1D models with 3D CFD cabin models and enables parallel development of both forms of models. The 1D model can capture complex thermal and climate system interactions while the 3D CFD cabin models can capture localized aspects of cabin comfort.

The 3D cabin models used for the study included both Conjugate Heat Transfer (CHT) and enhanced cabin models. The cabin model relies on simplified Evaporator Blower Assembly (EBA) model to convert outputs from the 1D thermal system model into cabin duct air-flow boundary conditions. The 1D model includes climate system model combined with simplified controls that can close the loop with the 3D cabin model to achieve the desired cabin comfort levels.

While the toolset is in active development, the proposed co-simulation approach has been applied to both cabin heating and cooling scenarios for different vehicle types and climate system architectures. The approach was successful in predicting cabin comfort metrics like breath level temperature and evaluate the impact on battery energy consumption. As a proof of concept, the approach has also been used to iterate on key calibration settings like evaporator target temperature that leads to desired cabin comfort while minimizing battery energy usage. In future, the approach can potentially be extended to more complex comfort models to provide deeper understanding of human comfort. On the contrary, it can also help with creating reduced-order cabin models to enable full system design space analysis.

Motorsport Technology Transfer Deploying Vehicle Simulation to the Masses

Theodor Ensbury[1] | theodor.ensbury@claytex.com
Nate Horn[1] | nate.horn@claytex.com
Isaac Rose[2] | isaacrose@penskeshocks.com

[1]Claytex USA, Inc., United States
[2]Penske Racing Shocks, United States

Motorsport's traditional role as the laboratory for the road has evolved in recent years. Contemporary contributions to technical advancement can now be felt in the sphere of engineering techniques and tools. Claytex have partnered with Penske Racing Shocks to bring vehicle simulation to the mid-level professional motorsport outfit, expanding the scope of who is able to utilize simulation to develop and improve their vehicles.

Progressive elimination of on-track testing sparked the development and adoption of driver in the loop (DiL) simulators and desktop-based vehicle dynamics simulation. Both have become common at the top levels such as Formula 1 or NASCAR. Dymola and Modelica enjoy a strong market presence at the highest tier but cost and resources have limited the transfer from the top to middle and lower levels.

Simulation goals for the mid-tier professional team often resemble those of teams in the top echelon. Augmentation of experience-based decisions with simulation data is often the first step. Next, more complex design changes and their potential effects are explored. Teams can then rationalize the impact of various changes, aiding development. One advantage for Penske Racing Shocks has been the ability to create a catalogue of various car parts – builds, assemblies etc – and then use simulation to put various virtual twins through their paces in different configurations. Impacts on vehicle behavior, and ultimately laptime are quick to follow, improving and refining the customer's performance.

For mid-level professional motorsport teams, the propagation of technologies such as data loggers in the past 15-20 years has been allied to a trend of affordability for data storage and computational resources. Simulation of their vehicles is now a feasible concept from a technical perspective as the required data and hardware is now available. However, barriers to the use of high-end market simulation techniques still exist.

Directly inspired by how Dymola is utilized at the top-level, Claytex have addressed these issues with Penske Racing Shocks. The process of creating a generalized GUI which can be utilized by the end user has been achieved.

Thermo-Fluid Modeling Framework for Supercomputer Digital Twins: Part 1, Demonstration at Exascale

Vineet Kumar[1] | kumarv@ornl.gov

Scott Greenwood[1] | greenwoodms@ornl.gov

Wesley Brewer[2] | brewerwh@ornl.gov

David Grant[3] | grantdr@ornl.gov

Nathan Parkison[3] | parkisonjn@ornl.gov

Wesley Williams[1] | williamswc@ornl.gov

[1]Fusion and Fission Energy and Science Directorate, Oak Ridge National Laboratory, USA

[2]Computing & Computational Sciences Directorate, Oak Ridge National Laboratory, USA

[3]Facilities & Operations Directorate, Oak Ridge National Laboratory, USA

A thermo-fluid modeling framework is being developed for ExaDigiT—an open-source framework for developing comprehensive digital twins of liquid-cooled supercomputers. The work is being conducted in two parts, and discussion is divided into two companion papers. The work documented in this paper focuses on the development of a cooling system library in Dymola for the Frontier supercomputer at Oak Ridge National Laboratory. The second part, outlined in a companion paper, focuses on a templating structure called Auto-CSM for easily creating model agnostic, physics-based thermo-fluid cooling system models for liquid-cooled supercomputers using a text-based schema. The cooling model is being developed using primarily the open-source Transient Simulation Framework of Reconfigurable Models (TRANSFORM) library. The library follows the templating architecture developed within the TRANSFORM library for modeling subsystems. A full-system validation was performed to validate a very simple model that is integrated with the system controls, and the results are presented herein.

Thermo-Fluid Modeling Framework for Supercomputer Digital Twins: Part 2, Automated Cooling Models

Scott Greenwood[1] | greenwoodms@ornl.gov

Vineet Kumar[1] | kumarv@ornl.gov

Wesley Brewer[2] | brewerwh@ornl.gov

[1]Fusion and Fission Energy and Science Directorate, Oak Ridge National Laboratory, USA

[2]Computing & Computational Sciences Directorate, Oak Ridge National Laboratory, USA

The development of digital twins for the purpose of improving the energy efficiency of supercomputing facilities is a non-trivial endeavor that is complicated by the difficulty of creating physics-based thermo-fluid cooling system models (CSMs). Within ExaDigit---an open-source framework for liquid-cooled supercomputing digital twins---a thermo-fluid modeling framework is being developed. This effort has been segmented into two with two companion papers describing each portion of the overall effort. Part 1 focuses on the development of a cooling system library in Dymola for the Frontier supercomputer at Oak Ridge National Laboratory. Part 2, this paper, describes an effort to create a template-based auto-generation methodology for CSMs, called *AutoCSM*. In this paper, an overview of the initial AutoCSM architecture and workflow is provided, along with a practical example using the Oak Ridge Leadership Computing Facility's (OLCF) Frontier supercomputer CSM. AutoCSM will (1) improve ExaDigiT's user accessibility by providing a flexible workflow for modularizing the creation of the CSM system and control logic, (2) decrease the development time of CSMs, and (3) standardize the method for incorporating CSMs into the ExaDigiT framework.

Efficient Simplified Models for District Energy CHP Systems

Zhanwei He | zuh45@psu.edu
Wangda Zuo | wangda.zuo@psu.edu

Penn State University, USA

This paper presents a simplified physics-based Combined Heat and Power (CHP) model developed in Modelica for district energy applications. The model prioritizes computational efficiency while maintaining accuracy, addressing the limitations of existing detailed physical models. It incorporates empirical correlation functions to streamline calculations in both the topping and bottoming cycles. The topping cycle utilizes look-up tables for gas turbine performance, while the bottoming cycle uses correlation functions for steam turbine output. The model's performance is validated against reference data, showing steady-state errors within ±8% and a 100-fold increase in simulation speed compared to Modelica models in ThermoPower. Additionally, the model demonstrates errors of 4.7% for water mass flow, 3.7% for steam mass flow, and 1.5% for steam turbine electricity, confirming its suitability for efficient and accurate district energy system simulations.

Optimizing Energy Consumption of a Plant-Scale Water-Cooled Central Cooling System via a High-Fidelity Simulator

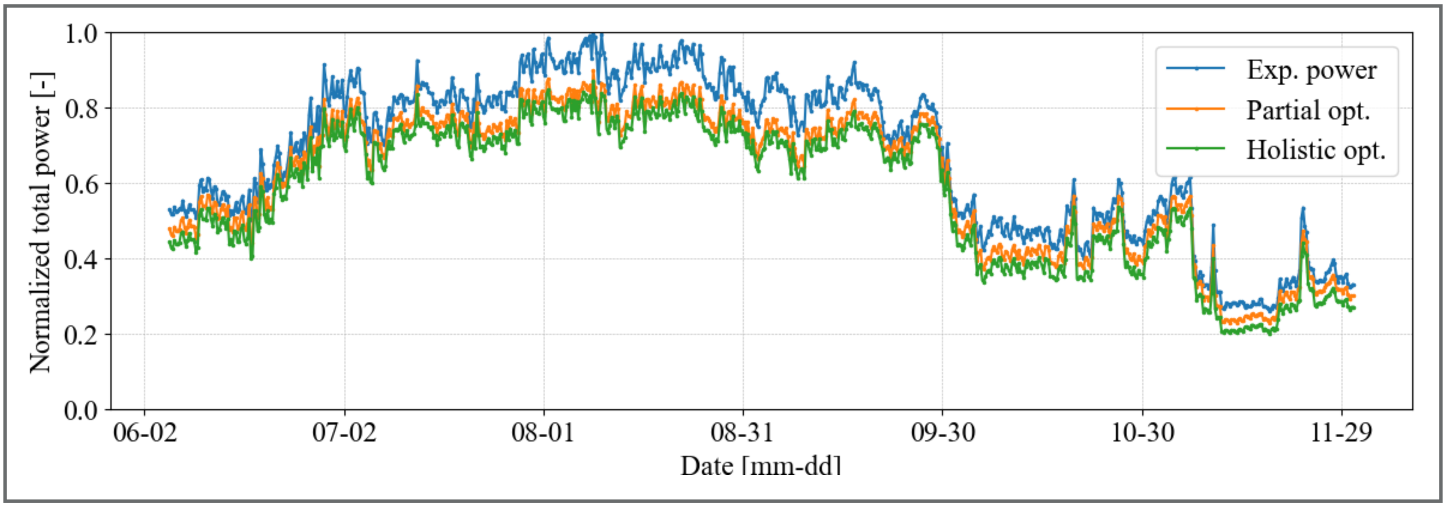
Myoungsoo Kim | rlaaudtn12141@gmail.com
Chanil Chun | chanil.chun@samsung.com
Minjun Song | m1njun.song@samsung.com
Haeun Yoo | haeun.yoo@samsung.com
Hyungsik Um | hyungsik.um@samsung.com
Jiwhan Lee | jhwan.s.lee@samsung.com
Sejun Park | sejun90.park@samsung.com

Samsung Electronics, South Korea

A heat, ventilation, and air conditioning (HVAC) system accounts for a substantial amount of the electricity consumption in a semiconductor plant in order to maintain desired air quality, including temperature and humidity. Particularly, a cooling water system, which comprises cooling towers, chillers, and cooling water pumps, is known to consume approximately 30% of the total electricity in the plant. Therefore, optimizing energy consumption of a cooling water system is a key to reducing operation cost and carbon emission. To this end, a high-fidelity simulator for a cooling water system was developed by utilizing physics-based models that were validated against numerous data. The simulator showed good performance with a mean absolute percentage error of less than 2.0% when predicting the total electricity consumption of six-month actual operation data. Along with the developed simulator, the optimal control strategy of the cooling water system was proposed utilizing a genetic algorithm (GA) to minimize the total electricity consumption while maintaining the system performance. It was found that the proposed strategy can achieve an energy saving by 14.0%, which is equivalent to approximately 4% of the total electricity consumption in a semiconductor plant.

Keywords: HVAC, electricity consumption optimization, semiconductor plants, central cooling system

Figure 1.
Comparison of normalized total power consumptions. Note that y-axis values were normalized by the maximum value for confidentiality reasons.



Model Coupling: SysML Extension for Physical Interaction and Signal Flow Simulation and Bidirectional Flow for Convective Transport Phenomena

Marcus Richardson[1] | marcus.k.richardson@boeing.com
Charles Manion[2] | charles.manion@nist.gov
Conrad Bock[2] | conrad.bock@nist.gov
Raphael Barbau[2] | raphael.barbau@nist.gov

[1]The Boeing Company
[2]National Institute of Standards and Technology

The Systems Modeling Language (SysML) is heavily used in industry and academia to architect systems from stakeholder needs and requirements. The system architecture must be linked to its verification activities. On the left side of the Systems Engineering V the verification activities play a key role in reducing the risk that the architecture will not meet its stakeholder needs and requirements. Furthermore, deriving requirements requires analysis, based on the hierarchical level of the source requirement, to the derivation. This results in industry struggling to find the best tools to link system architectures with the models that are used to ensure their suitability to the system requirements.

The SysML Extension for Physical Interaction and Signal Flow (SysPhS) specification, library, and simulation translation was created to enable system architects to build models for simulation in their system architecting tool. It incorporates capabilities that are common to Modelica, Simulink, and Simscape. While a systems architecting tool like CAMEO might not be the best tool for high fidelity and other complex simulations, engineers doing system verification during the early stages of its design (on the left side of the V) would benefit from the ability to perform trade studies and build confidence in their architecture through easily generated simulations. It further provides the systems engineer the ability to evaluate their models without rearchitecting them in a simulation tool.

The SysPhS specification lacks a convenient means of simulating bidirectional convective transport phenomena. The current specification and the associated libraries are well suited for any system that may be fully defined by what is flowing and the potential that is driving the flow. Examples of such a system, are heat transfer by conduction, flow of electricity, the translational movement, and transfer of incompressible fluid. Physical modeling interfaces include two variables, the product of which equate to power, such as force and velocity, or entropy and temperature. However, there are two major issues for convective transport phenomena: 1) mass flow and enthalpy flow are not included in the specification and 2) bidirectional convective transport phenomena simulation components to have knowledge of their neighboring components.

A update to SysPhS is proposed to add combined mass and enthalpy flow. Bidirectional convective transport is addressed borrowing from the existing Modelica Stream Component semantics of computing an outflow specific enthalpy and an inquired value for inflows. The method is tested with a simple system model in SysPhS, comprised of two flow sources and a fixed volume, all connected by a single three-way connector. The same model is translated into Modelica and Simscape code using an existing SysPhS translator with negligible differences in simulation results. This method seems to be a way to reliably simulate bidirectional convective transport phenomena within a systems architecture model. This presentation is a follow on to the 2017 MODPROD keynote presentation by Conrad Bock.

VENDOR ABSTRACTS

Modelon

Modelon offers systems modeling and simulation software that accelerates product innovation, development and operations in a range of industries. Modelon's flagship product, Modelon Impact, is a cloud-native system simulation software platform featuring a collaborative browser-based interface and thousands of proven models and components spanning a broad range of applications. Headquartered in Lund, Sweden, and with global reach, Modelon is an expert industry leader in model-based systems engineering with a focus on leveraging open standard technologies.

Modelon Impact is a next generation system modeling and simulation platform, leveraging the benefits of web and open standard technologies. With openness at its core, Modelon Impact supports standards such as Modelica, FMI, Python and REST. The user-friendly browser interface provides modeling experts the tools they need to create, simulate, and experiment. Steady-state or dynamic simulations can be obtained from the same model, reducing effort to get an answer. Finally, the Modelon Impact API enables user-specific workflows through Python-based custom functions, and deployment of models to non-experts via targeted web applications or Jupyter Notebooks.

JuliaHub

JuliaSim: Modern Modeling and Simulation powered by Machine Learning

JuliaSim is the next-generation, cloud-based platform created to enable model-based design using modern scientific machine learning (SciML) techniques and equation-based digital twin modeling. JuliaSim is built on the Julia programming language, offering unmatched speed and performance, with real-world applications demonstrating significantly faster simulations.

JuliaSim encompasses block diagrams, acausal modeling, state transition diagrams, and a differentiable programming language, all within a single environment.

Design Multiphysics Models Faster, Better

- Combine differentiability/symbolic manipulation
- Integrate graphical/text-based workflows with drag-and-drop modeling
- Component libraries across engineering domains
- Sophisticated AI: Leverage machine learning and real-world data
- Deterministic autocoding with traceability/reproducibility
- Modern development workflows (git, CI/CD)

Design and Calibration

JuliaSim supports the creation of both controller and plant models needed for system engineering.

- Model calibration: Efficiently leverage real-world data
- Identify missing physics: Use the same data to discover gaps in your models

Beyond Design: Complete Product Lifecycle Support

JuliaSim extends beyond the design phase to support the entire product lifecycle by collecting real-world telemetry. JuliaSim enables operations and diagnostics/prognostics applications:

- Use tuned models in the field to optimize operations
- Identify impending failures and their causes
- Retrain physical component models to account for wear/aging

Julia is a high-performance programming language designed for technical and scientific computing. Combining the speed of low-level languages like C with the ease of use of languages like Python, Julia excels in tasks involving large-scale data analysis, machine learning, numerical simulations, and more.

JuliaHub is a cloud-based platform that empowers users to harness the full potential of Julia for large-scale modeling, simulation, and optimization. With tools like JuliaSim, it provides an end-to-end environment for developing, deploying, and analyzing models across a range of engineering domains.

DASSAULT SYSTEMES

You will discover the latest news and perspectives regarding Dymola and underlying technologies, as well as the portfolio of libraries. Also included: latest standards support and examples of workflows involving native and web clients of the Dassault Systèmes offer. Highlights of the vendor session include:

- Improved support for parameter management in Modelica and for FMUs.
- Improvements for co-simulation of FMUs.
- Faster simulation for some important types of models.
- Support for System Structure and Parameterization, SSP 2.0
- Improved support for version management in Git
- A surprise product reveal.

XPI

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XPI is an engineering firm based in Waterloo, Canada, and an authorized distributor of ESI's multi-physics system simulation software SimulationX. Our engineering services include modeling, prototyping, digital twins, and software development. We serve businesses in industries such as automotive, heavy machinery, and aerospace, that design and manufacture complex machines.

The multi-physics simulation software SimulationX is a highly intuitive systems modeling tool that comes with integrated model libraries, and open interfaces. The software is used to design and verify complex systems and machinery. It offers exceptional ease of use and quick calculation, making it a popular choice among engineers.

SimulationX highlights include:

- High quality 3D view that visualizes the model as you build
- Fully integrated multi-domain libraries and 3rd party Modelica library support
- TypeDesigner to generate Modelica code using a graphical user interface
- Flexible interfaces: FMU import and export, C-Code export, HIL platforms, and more
- Integrated Jupyter Notebook python scripting

CLAYTEX
A TECHNIA COMPANY

Claytex, a TECHNIA Company, delivers exceptional tools at the cutting edge of vehicle simulation. With over 20 years of system simulation experience using Dymola and Modelica in the Motorsport and Automotive sectors, we know that no single challenge is the same. So, we apply an adaptable, flexible and solution-oriented approach, empowering our customers to achieve their technical and business objectives.

Our autonomous vehicle simulation solution developed in house, is built around rFpro and provides physics-based sensor models enabling automotive manufacturers to test, develop and deploy AV solutions into the real world without compromising on safety.

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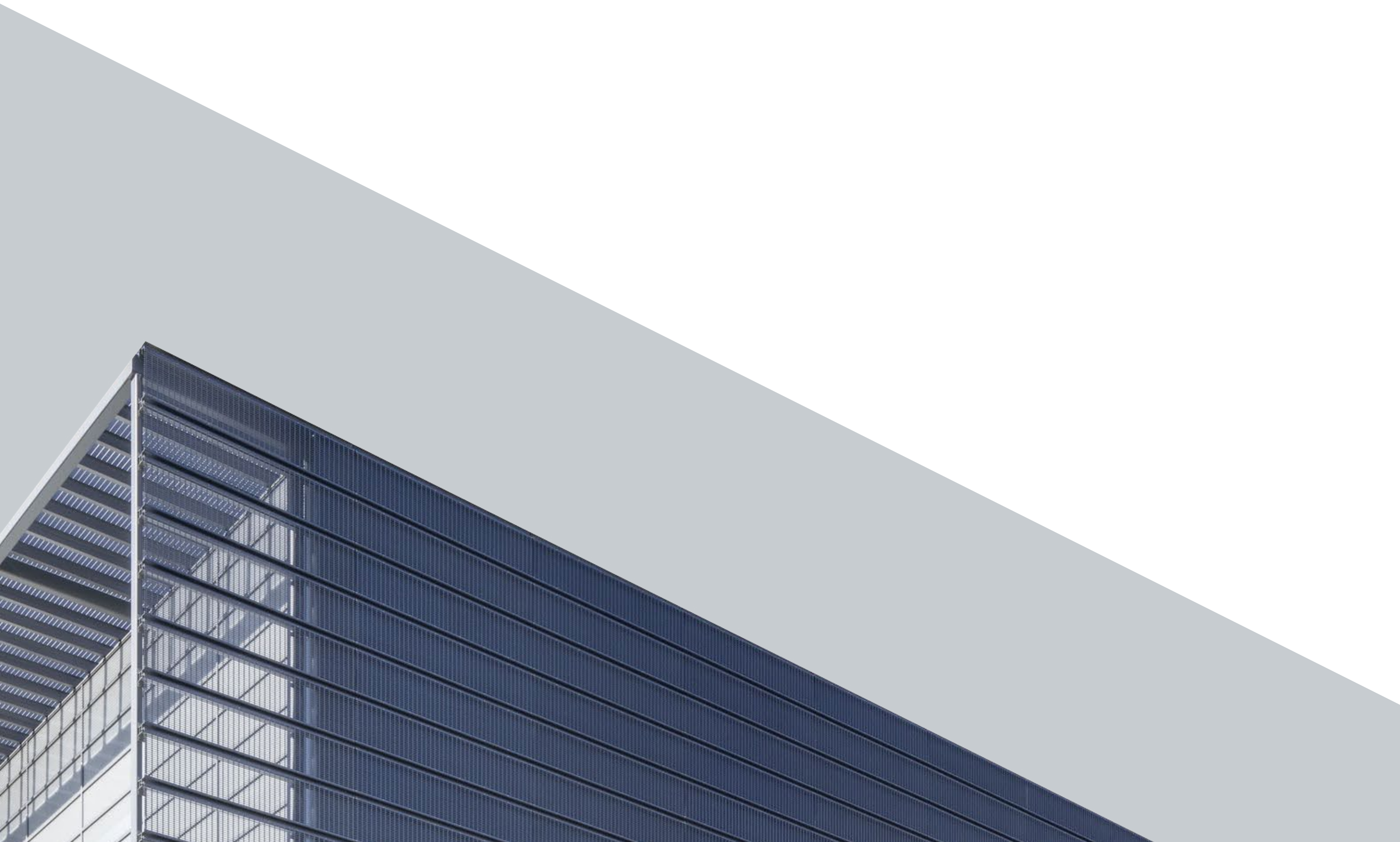

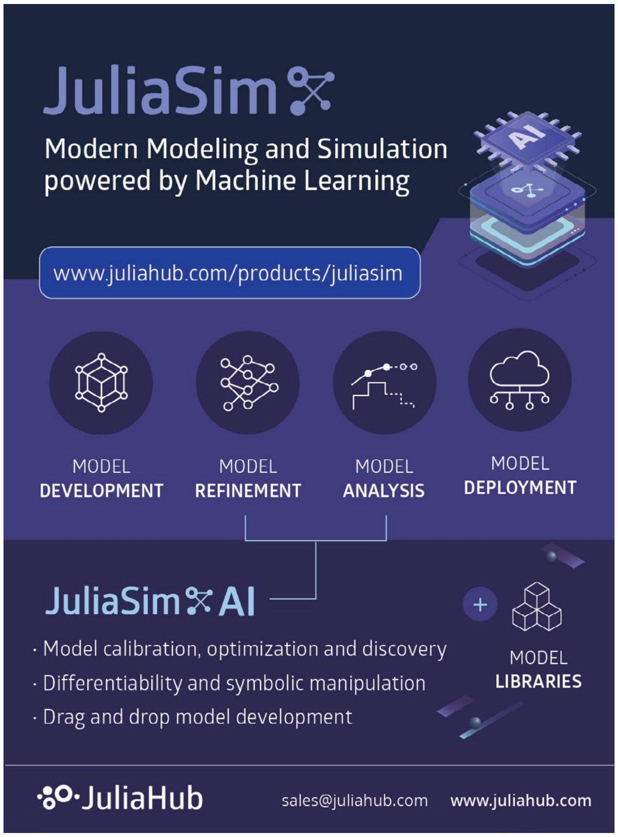
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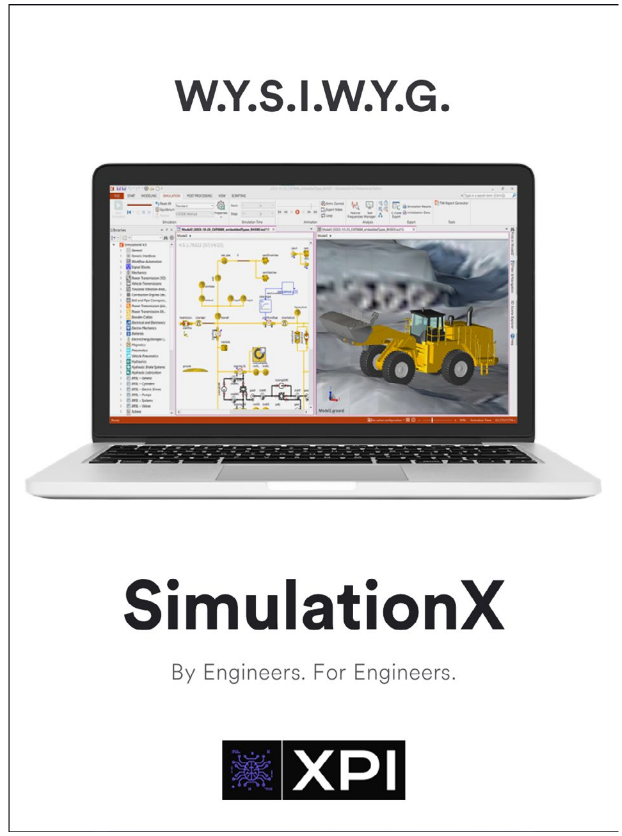
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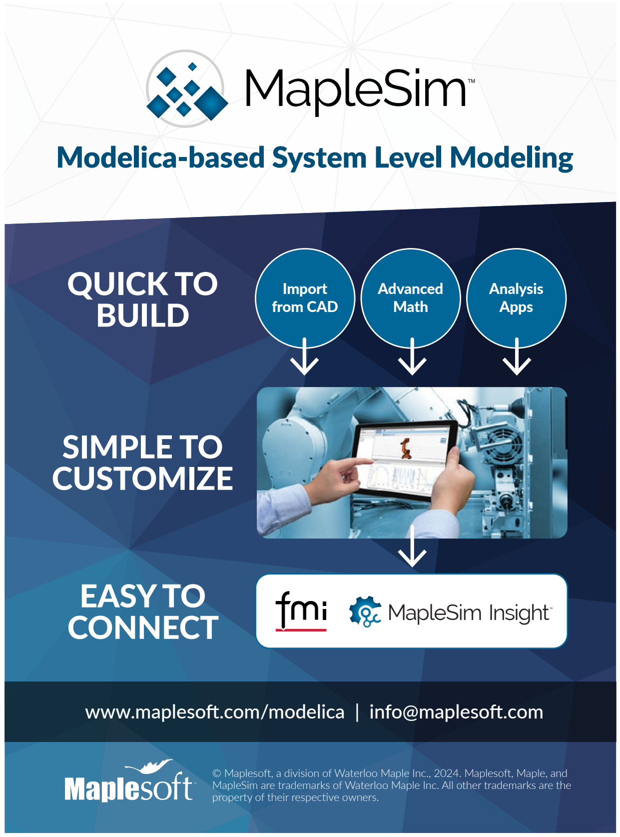

Modelica

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Modelon

GOLD
JuliaHub / XPI / Claytex / Dassault Systèmes

SILVER
Maplesoft


Modelica
Association