Proceedings of the 2014 Winter Simulation Conference
A. Tolk, S. Y. Diallo, I. O. Ryzhov, L. Yilmaz, S. Buckley, and J. A. Miller, eds.

PARTIAL PARADIGM HIDING AND REUSABILITY IN HYBRID SIMULATION MODELING USING THE FRAMEWORKS HEALTH-DS AND I7-ANYENERGY

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ABSTRACT

Many complex real-world problems which are difficult to understand can be solved by discrete or continuous simulation techniques, such as Discrete-Event-Simulation, Agent-Based-Simulation or System Dynamics. In recently published literature, various multilevel and large-scale hybrid simulation examples have been presented that combine different approaches in common environments. Many studies using this technique in interdisciplinary projects have the problem of a different model understanding. In this case, paradigm hiding can help in domain-oriented communication with non-technical experts avoiding unnecessary paradigm discussions. Another problem is that already solved problems are often not reusable in future scenarios and have to be modeled and validated in similar studies from the scratch. This paper presents selected concepts that can help to build domain specific frameworks with reusable components in AnyLogic 7 and depicts two examples; HealthDS for prospective healthcare decision support and i7-AnyEnergy that can be used for building innovative energy scenarios.

1 INTRODUCTION

New innovations have the power to improve existing services, processes or to solve dedicated complex real-world problems. Furthermore, they are important for economic growth and competitiveness of a country (Comin and Hobijn 2008; Rao et al. 2001). However, it is essential to learn about their impacts prospectively, before their application and market launch. In particular, in safety-critical domains (e.g., healthcare, aviation) it is fundamental to support decision-makers when assessing new technologies, as the product's quality often affects the quality of people's life and even nation's health.

There are different techniques that can be applied within the scope of innovative scenario assessments. A possible decision support can be done by prototyping which is a possibility to allow real-world experiments with new products, but in many cases it takes a high amount of time and is very cost-intensive. Often it is even not possible to build a suitable prototype and to run real-world experiments, because of not available future environments and other aspects (e.g., life-threatening). Simulation and modeling is another common method to guide decision-making in such situations representing complex structures and systems by abstract models. There are different approaches that can be used within this scope. Discrete-Event-Simulation (DES), Agent-Based-Simulation (ABS) and System Dynamics (SD) are most common to build models enabling to incorporate probabilistic or continuous structures. Hybrid simulation is a technique that allows to combine different paradigms in a common simulation. In particular, this method is appropriate for large-scaled and interdisciplinary studies considering structures at high abstraction levels as well as representations at microscopic and detailed levels. However, combining continuous and discrete techniques to solve a problem is usually not straight forward and there are many publications in current literature proposing hybrid approaches in different domains (e.g., Zulkepli, Eldabi, and Mustafee 2012).

Before starting to develop a new model it is important to select a level of abstraction and to decide which simulation paradigms are appropriate for solving a dedicated problem. A further question is usually related to the choice of a software package that can meet all requirements or the decision to implement a model by own program code. Following these steps the solution finding process is mainly paradigm-oriented and many modeling decisions are mostly dependent on the selected simulation technique and less on the problem that has to be solved. This can easily lead to, e.g., wrongly validated models in interdisciplinary projects. To prevent technical discussions with domain experts and saving time, it is important to switch the conjoint process to an abstract and paradigm-free modeling level. This helps to build and validate models focusing on the problem and not on technical modeling aspects. Furthermore, reuse of already done work in future studies (e.g., by modularization) can speed up the decision-making process extremely, as in most cases only few parts are different in similar projects.

This paper proposes in section 3 selected concepts and best cases to build domain-specific frameworks in order to benefit from paradigm hiding and reusability in hybrid simulation modeling. It will be mainly explained how modules can be designed and how such components can be connected to each other when developing dedicated scenarios by toolbox elements. In this context it is important to determine the levels of abstraction for the components and how they interact. For implementation purposes we are using the multi-method simulation software AnyLogic (AnyLogic 2014) which is appropriate within the field of hybrid simulation and that is suitable for implementing most of the concepts presented in this work. Furthermore, it will be outlined why the term partial is important for flexibility of such frameworks and how paradigm hided modules can be connected to SD, ABS and DES components.

In section 4 several modeling examples of the *HealthDS* will be presented. It will be explained how this framework can be used to build models within the scope of prospective healthcare decision support and highlights the abstract *Onion-Rings-Model* that can be used to calculate moving times of Rescue Vehicles (RV) in particular. Finally, section 5 includes the hybrid simulation framework *i7-AnyEnergy* for modeling renewable energy generation and storage grids. It is explained which of the presented concepts are used in this framework and a case study of a virtual storage plant model is given.

2 RELATED WORK

The scope of this paper is related to various topics. Particularly, hybrid simulation modeling, conceptual design and solving decision-making problems in general are relevant for building frameworks and interdisciplinary scenarios. Furthermore, a major field is hierarchical and component-based modeling. Related domain specific topics will be discussed more in detail within the sections 4 and 5.

Solving decision-making problems is a prominent topic in various publications. In Iassinovski et al. (2003) an approach has been presented, how to proceed from the *problem domain* to the *solution domain*. Chatha and Weston (2006) argues that there is a use of decision-support framework and presents an approach that combines different modeling methods aiming to management of decision support.

Hybrid simulation modeling is in focus of many academic publications. There are several models and applications that are using different paradigms in a common environment to solve problems at different abstraction levels. Brailsford et al. (2013) presented a discussion about the use of hybrid simulation within the field of health and social care. General concepts guiding the development of hybrid simulation models have been presented by, e.g., Chahal, Eldabi, and Young (2013). The authors propose a process that allows to decide, if hybrid approaches are appropriate for a dedicated problem solving. In Chahal and Eldabi (2008) different hybrid formats have been introduced that can help to arrange SD and DES models in common environments.

Modeling real-world problems is a challenging task. The field of conceptual modeling helps to decide which level of abstraction is appropriate and what are the major structures to model. According to Robinson (2013), "it is probably the most important aspect of any simulation study." For example, within the scope of Prospective Health Technology Assessment (Kolominsky-Rabas et al. 2014) modeling of conjoint problems with domain experts can be achieved by complementary non-formal conceptual domain models (Gantner-Bär et al. 2011) that allow to gain a common model comprehension for both; the domain and technical experts. However, there is a need to transform such models to technical simulation models which is usually a difficult process.

Hierarchical and component-based modeling is a popular approach within the area of software engineering. Cetinkaya, Verbraeck, and Seck (2010) justifies the mapping of software engineering approaches to the field of simulation and modeling and argues that this will help to manage large-scaled and complex models more efficiently. However, the authors identified a gap between conceptual modeling and the phase of model construction and proposed a conceptual modeling language in order to express how technical components are mapped to domain elements.

In the following sections we propose an approach to build domain-specific frameworks developing problem-oriented models together with domain experts. Hiding technical structures behind domain related modules can help to develop runnable scenarios without explicit distinctions between conceptual and technical modules.

3 BUILDING FRAMEWORKS

As already mentioned previously, developing and validating simulation models in interdisciplinary projects is not trivial. To allow a common understanding, all stakeholders must be able to connect the problem to the model. In complex and large-scaled scenarios it can become a long process, as many domain experts usually don't understand technical formalisms. Discussions about appropriate simulation techniques and coupling of elements between different modeling paradigms are time-intensive and often not necessary. Furthermore, fast changes of study designs and parameter configurations in already existing implementations are important to evaluate different possible solutions as fast as possible. Particularly, this can be used for adaptions of already implemented use-cases, e.g., to other regions, different time intervals or having the ability to extend existing scenarios.

To master these and other challenges, a problem can be divided into smaller unique problems. The idea is to have specialized modules for dedicated problem types and components that can be reused in similar scenarios and in studies with similar contexts. In software engineering this kind of reusability can be achieved by application of frameworks which are "abstract designs for solutions to a family of related problems" (Johnson and Foote 1988).

In simulation and modeling modularization can be used to build frameworks with elements that can be combined to scenarios for studies of related problems and domains. Each module within a framework is standing for an own smaller problem and can be used with input data (e.g., for a particular region) to produce output metrics. In the following, selected concepts will be presented that allow to develop domain-specific frameworks.

3.1 Designing Components by Partial Paradigm Hiding

In Djanatliev and German (2013a) the *Level-Based-Architecture (LBA)* has been presented that allows to distinguish between different levels of modeling when developing new scenarios within the scope of prospective assessments of innovations. The following four levels have been mentioned:

- Inter-module level
- Configuration level
- Model level
- Calculations level

Going top-down, at the inter-module level domain specific elements can be used and connected to each other. At the configuration level each module can be configured by input data or connected to other modules that produce data to be able to run. The model level can be used to build models using known modeling paradigms, e.g., DES, ABS or SD. Finally, the calculations level allows to go more in detail, e.g., splitting SD stocks into dimensions (e.g., people by income, total energy in proportions of gas, wind etc.).

In paradigm hided hybrid models the actual implementation of components is not important, so that the modules are treated as *black-boxes* using interfaces to communicate with other components. Hence, the focus is not on knowing which paradigm has been applied behind a module, but on the problem the component has been designed for.

Using only provided framework elements lead to a complete hiding of the simulation paradigms in interdisciplinary studies. Figure 1 shows an example for scenario building by paradigm-hidden components. Thus, output metrics of modules can serve totally or partially as inputs for other components and they can be a part of common scenario results.

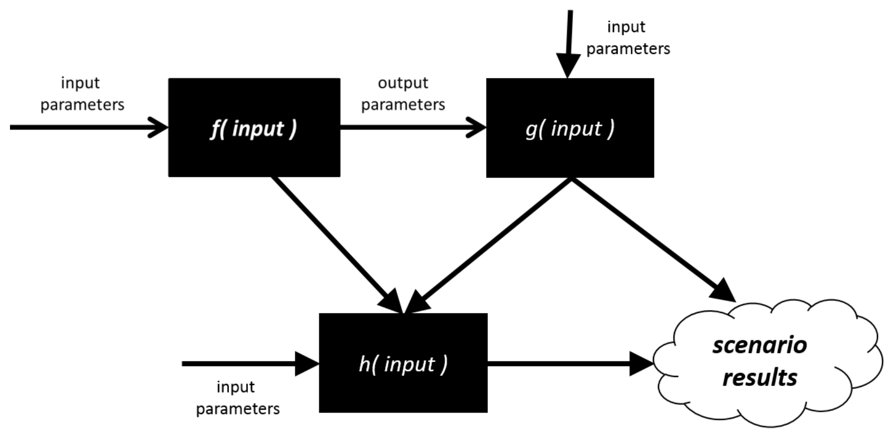

Figure 1: Example solution finding by reusable framework components (black-boxes). The abstract functions $f(input), g(input)$ and $h(input)$ can be solved by different modeling paradigms.

Following the LBA, paradigm hided modules can be designed at all levels above the model level. Collecting existing components to sets allows building frameworks. However, we experienced that in many cases it is not possible to prepare generic paradigm-hidden components for all situations. Hence, the framework has to be extendable and the components must be reusable in new models. For example, combining available modules to new components (e.g., different processes to a new process sequence) leads to a more powerful framework. Further flexibility can be achieved by paradigm specific interfaces. This helps to build extensions for specialized studies by modeling at the model level of the LBA. This means that parts of the resulting overall model are not paradigm-hidden and the interfaces of black-box modules must provide mechanisms to connect them to DES, ABS or SD components. According to this necessary flexibility the term *partial* has been added to the title.

3.2 Connecting Components

In Figure 1 the black-boxes have to exchange parameters without knowing which modeling paradigm the other boxes use. Therefore, each black-box has defined its provided or required interfaces which encapsulate the modeling paradigms. A connection between interfaces can be established by registration at a central registration instance or by sending registration messages at the beginning of the simulation to connected components; e.g. in Figure 1 the component implementing $f(input)$ and the component implementing $g(input)$ are connected via dedicated interfaces.

After a connection at the inter-module level of the LBA has been established, configuration parameters, for the configuration of components, or run time input and output parameters can be exchanged. Parameters can be values, messages or objects. The type of a parameter is defined by the type of the interface. Interfaces can be reused, because they are parametrized with an identifier. Two interfaces with the same type, but different identifiers will not join. This automatically ensures that only interfaces of the right type and with identical identifiers will establish a connection; e.g., in energy scenarios heat and electricity flows implement the interface type energy flow, but have two different identifiers - heat and energy.

3.3 Data Components for Input Modeling

Usually, many sources of input data are required in large-scaled simulation models. Particularly, scattered data loading leads to difficulties in model adaptions and to implementation problems, as each module has to be configured separately and equal sources are loaded several times.

Configuring modules at the configuration level of the LBA can be done by additional data components (DC) instead of direct configuration. Hence, this can help to perform input modeling for complete studies at one common location. Data can be loaded from data bases, excel files and other resources. Within the DCs loaded information can be prepared for usage (e.g., converting data) and combined with already loaded elements. Connections between DCs and other components can be achieved in the same manner as between modules at the inter-module level of LBA. The output is a data packet which serves as input data object for connected modules. Accessing data from received packets can be done via interfaces. Finally, data components are responsible to update data during simulation runs.

4 HEALTH DS: HEALTHCARE DECISION SUPPORT

Prospective healthcare decision support by hybrid simulation allows to assess and to optimize healthcare innovations, before a product has been designed and developed. In Djanatliev and German (2013b) general concepts have been introduced including an approach about how agents and DES entities can be generated from SD environments. Furthermore, two case studies have been presented answering *what-if* and *how-to* questions supporting the decision-making.

In this section we focus on selected concepts of the *HealthDS* framework that can be used to build evaluation scenarios and to support decision-makers. Particularly, reusable rescue service vehicles, the *Onion-Rings-Model* and generic process libraries will be presented.

4.1 Framework Overview

The framework has been implemented in AnyLogic 7 (AnyLogic 2014). This software package is appropriate for multi-paradigm modeling and includes further features that are important within the scope of framework building. Among others, hierarchical modeling by nested `Agent` objects, exporting libraries, improved inheritance handling (in AnyLogic 7) and individual extensions by own Java code. Figure 2 depicts an example scenario with *HealthDS* components at the inter-module level.

Particularly, the following reusable components are a part of the framework: Population Dynamics, Disease Dynamics, Error Injector (generating errors, e.g., wrong resource usages), Geo Dynamics (region modeling by districts using the element picker feature of AnyLogic 7), specialized and generic process libraries and process selectors, rescue service vehicle (with configurable processes), hospitals (with configurable processes for diagnosis and therapy), sensitivity/specificity table, pre-defined data components (e.g., loading external data from files), etc.

HealthDS includes modules for different LBA levels. For example, Population Dynamics (PD) can be used at the inter-module level connecting further components by port connections. Additional (paradigm-hidden) PD-modules with SD auxiliary interfaces can be connected directly to SD models. This realizes the *partial* paradigm-hiding concept and ensures the flexibility of the framework.

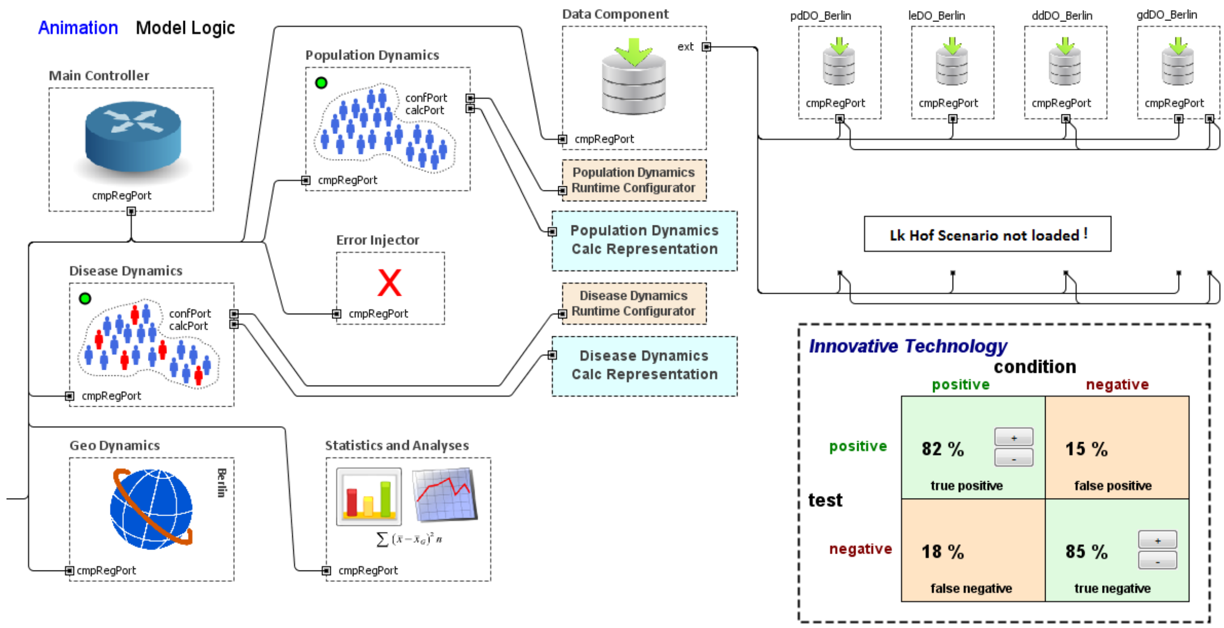

Figure 2: Example extract of an inter-module level *HealthDS* model.

4.2 Generic Process Libraries

Processes and clinical pathways are important components in healthcare scenarios. Using *HealthDS*, affected patients can traverse different predefined workflows, after the generation of agents in ABS components. Processes can be implemented by the elements of the new Process Modeling Library in AnyLogic 7 (or Enterprise Library in AnyLogic 6).

Modeling and validating clinical pathways is challenging, as usually there are different interpretations of domain experts. Thus, once a consensus for a sequence of actions has been found and a modeled process has been validated, it is important to prepare it for reuse in other scenarios. Within the scope of *HealthDS* this can be done by unique process modules. Combining existing processes or building sequences (e.g., diagnosis, treatment) results in new reusable modules. All of them are implementing the common interface `IProcess`. Different components (e.g., hospitals) may contain processes. As such pathways are usually disease specific, the corresponding components cannot be reused in scenarios with other diseases. For this reason, the *HealthDS* framework provides generic process libraries that can be used as placeholders for processes inside generic components. Dedicated process selectors for modules with libraries can be used to select and configure a process (e.g., figure 3, left). New processes and sub-libraries must implement such a process selector and should be added to a common process library.

4.3 Rescue Service Vehicles

Rescue service vehicles (RSV) are elementary components in scenarios with emergency situations. Dependent on the region and quality of the provided rescue service, it can be crucial for saving people's lives. There are different types of vehicles (e.g., specialized equipment on board, with/without doctor etc.) that can have different effects on the healing success. In Djanatliev et al. (2012) a case study with Mobile Stroke Units (MSU) has been presented. The aim had been to evaluate these innovative vehicles for stroke treatments on-site at disease occurrence location saving crucial time. The *HealthDS* framework provides generic and configurable vehicles at the inter-module level. The black-box of the vehicle contains the state chart depicted in figure 3. Thus, a generic process library (section 4.2) is being activated after entering the busy state. A dedicated process can be selected by the process selector of the generic library.

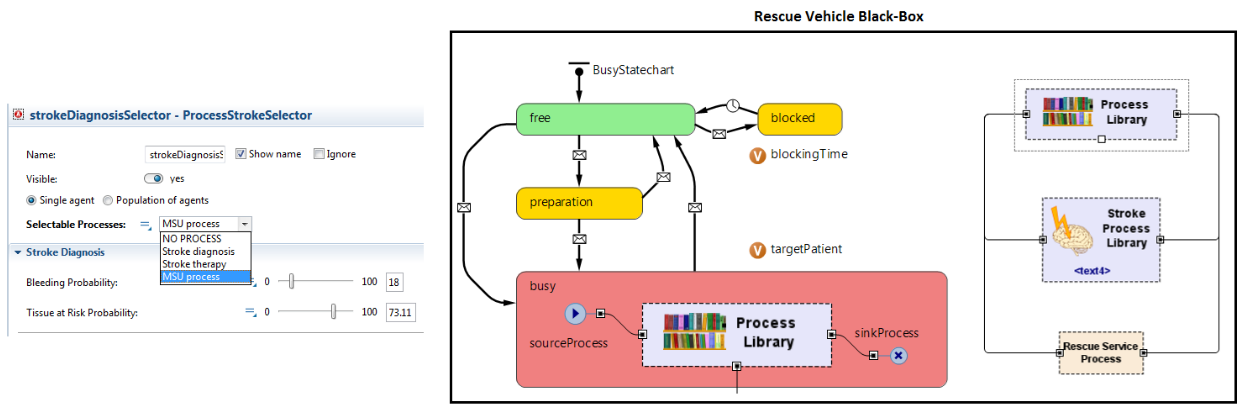

Figure 3: Using a process selector configuring a process for a rescue vehicle.

4.4 Onion-Rings-Model

Calculating travel times for RSVs can be done by several techniques. The most detailed solution can possibly be achieved by traffic simulations for a previously defined region. However, such an approach can reduce the simulation performance without providing additional insights and it may take much time to model realistic scenarios. Furthermore, additional efforts have to be invested when adapting a simulation to other regions. According to a different focus in healthcare simulations, an abstract and simplified model for calculations of traffic times has to be used instead of implementing complementary micro-simulations of traffic scenarios. Usually, raw data of time distributions for short distances are available from rescue service departments and in already published literature.

The *Onion-Rings-Model* is an abstract model for simplified calculations of travel times. When configuring a vehicle, a radius R can be defined according to the published distance of available time data. The euclidean distance from the source to the destination $dist(src, dest)$ can then be divided into rings, as presented in figure 4.

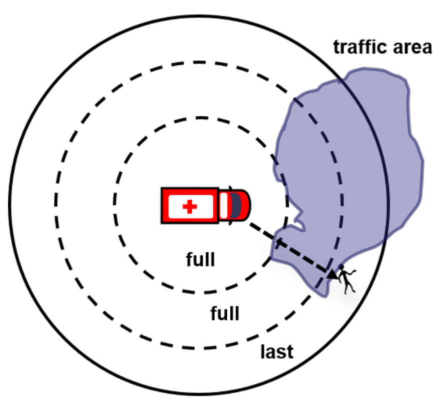

Figure 4: Abstract representation of the *Onion-Rings-Model*.

Two different distributions can be defined in order to distinguish between a fully traversed ring (sampled by $sampleFull()$) and a last ring (sampled by $sampleLast()$) which will be only partially traversed. The number of full rings can be calculated by the equation 1. Equation 2 allows to calculate the travel time at run time. Additional values for delays (e.g., traffic at rush hour) and accelerations (e.g., highways) can be added in individual studies.

$$n = \left\lfloor \frac{dist(src, dest)}{R} \right\rfloor \tag{1}$$

$$t_{dest} = sampleLast() + \sum_{i=1}^{n} sampleFull() \tag{2}$$

5 I7-ANYENERGY: RENEWABLE ENERGY GENERATION AND STORAGE GRIDS

The increasing utilization of renewable energy sources like solar radiation and wind leads to an increasing fluctuation of the power generation. This fluctuation can be a problem for the quality and stability of the power supply if no appropriate measures are taken. For the investigation of new technologies in this context, the hybrid simulation framework i7-AnyEnergy has been created, using the introduced concepts like LBA, partial paradigm hiding, and reusability. It is implemented with the simulation framework AnyLogic introduced in the previous section. The following chapter provides an overview of the tool first, after that a case study of a virtual storage plant for the provision of balancing power is presented.

5.1 Framework Overview

The hybrid simulation framework described in Bazan and German (2012) and Bazan and German (2014) is a tool for the fast construction of renewable energy generation and storage grid simulation models. It combines electricity and heat together with natural gas and communication over messages. On the model level of the LBA the SD paradigm is used for energy flows whereas control decisions are modeled as state charts; e.g., see component μCHP (micro Combined Heat and Power) in figure 5 (right). These paradigms are hidden by using the described connection concept. Therefore, the components can be easily connected on the inter-module level of the LBA, creating a new component.

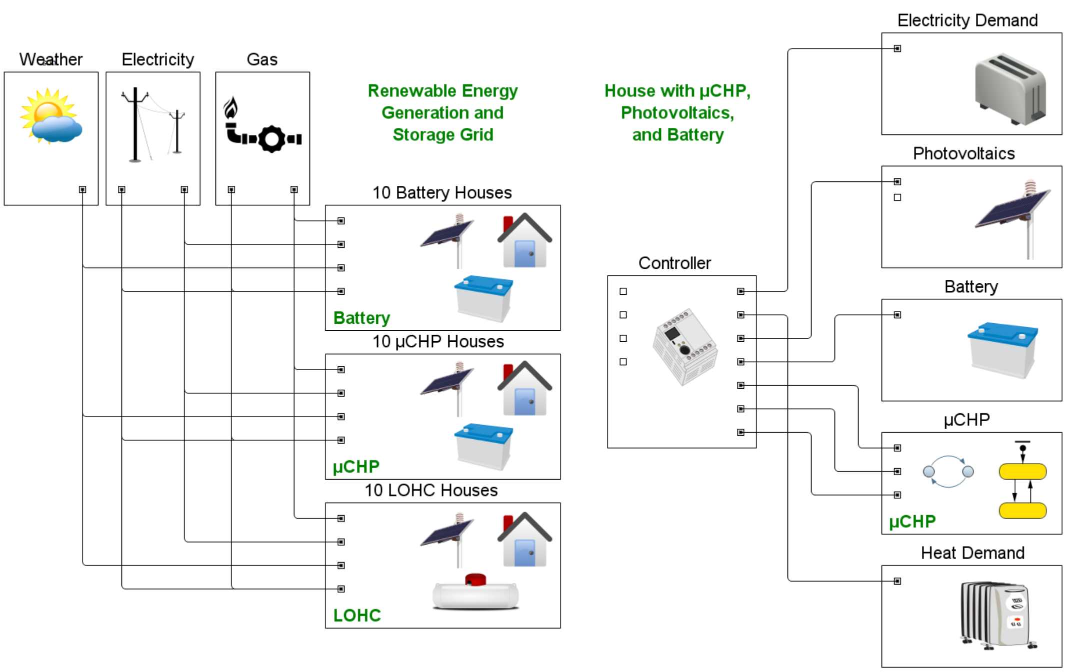

Figure 5: Hybrid simulation model of a renewable energy generation and storage grid with 10 μCHP house components(left), simulation model of a single μCHP house component with photovoltaics, battery and μCHP connected to a controller (right).

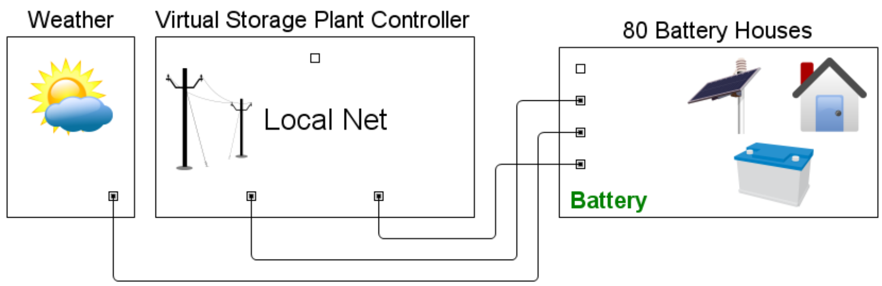

Figure 6: Virtual storage plant simulation model with 80 houses, each equipped with photovoltaics and a battery.

Several reusable components for the energy generation (μCHP, photovoltaics (PV)), energy consumption (electricity demand, heat demand), and energy storage (battery, Liquid Organic Hydrogen Carrier (LOHC) (Teichmann et al. 2011), heat storage) are available in i7-AnyEnergy. These components can be configured according to the configuration level of the LBA and combined to differently equipped house types. In figure 5 (left) a hybrid simulation model of a renewable energy generation and storage grid with ten houses with PV and battery, ten houses with PV, battery and μCHP, and ten houses with PV and LOHC is shown.

5.2 Virtual Storage Plant Case Study

In Germany, a single battery of a house with a power output of 14 kW and a capacity of 10 kWh cannot be used to sell positive or negative control power at the balancing energy market, because an output of 1 MW is required at least. However, this requirement can be met when 80 houses with a power output of 14 kW of a single battery do act together. Each house of the virtual storage plant model of figure 6 is additionally equipped with a PV with 6 kW_{peak}. The control strategy is the maximization of the own consumption of the energy from the PV. Figure 7 (top) shows that the virtual storage plant has the potential to sell mainly negative control power on dark winter days when the combined battery energy level is low, whereas on sunny summer days the virtual storage plant offers mainly positive control power (figure 7 (bottom)).

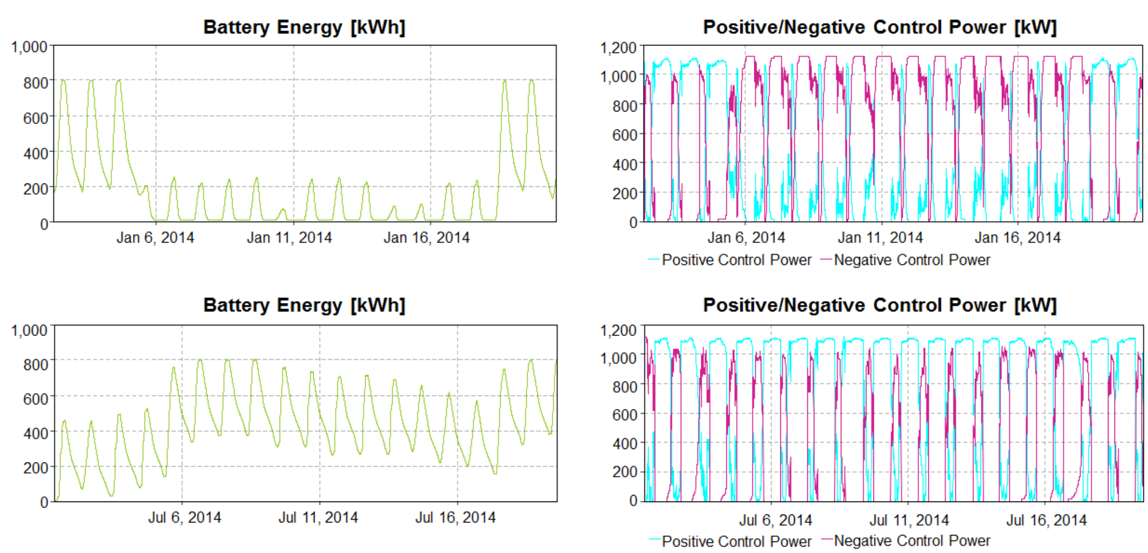

Figure 7: Snapshots of the simulation run of the virtual storage plant model at winter time (top) and at summer time (bottom).

6 CONCLUSIONS

When assessing innovative scenarios, decision-making can be guided by hybrid simulation and modeling. Aggregated and "bird's eye view level" problems can be solved together with detailed and low level structures. In interdisciplinary projects it lacks often on a common model comprehension, according to technical and paradigm-oriented modeling methodology. Therefore domain oriented modeling techniques are required in this field.

This paper presents selected concepts that are essential to build powerful domain specific frameworks with reusable components. It discusses the use of paradigm-hidden modules while solving problems in projects with several domain experts. Furthermore, reusability is essential to benefit from already done work and prevents modeling and validation of similar scenarios from the scratch. Building domain-specific frameworks can close this gap and provides *black-box* modules that can be reused in different contexts. As it is not easy to build components for all kind of studies prospectively, it should be possible to extend existing frameworks and to use paradigm-hidden modules in models with paradigm-oriented structures. This is why the term *partial* is important within the scope of this work.

Two example frameworks have been presented that are using the concepts presented in this paper. *HealthDS* can be applied within the scope of prospective healthcare decision support and *i7-AnyEnergy* is appropriate to evaluate innovative energy scenarios. Both have been implemented using the software package AnyLogic 7 (AnyLogic 2014) which provides functionality for framework building, hybrid simulation, hierarchical modeling, inheritance and other features that are important to implement the presented concepts.

In general we have learned that building new frameworks is a challenging and time-intensive task and it is much easier to develop non-generic components. However, it is worth to make necessary efforts, particularly in situations where scenarios have to be adapted to similar contexts, or where time for decision-making is limited. Furthermore, we experienced that in interdisciplinary projects a common model comprehension leads to better and more reliable validation results. Reusing already validated modules can speed-up the modeling and leads to time and costs savings in future studies in particular. A possible threat can be a missing acceptance to use a framework according to a not available training willingness. In a nutshell, although it is time-consuming to develop frameworks, there are many valuable advantages in similar and future studies.

ACKNOWLEDGMENTS

This work has been partially funded by the German Federal Ministry of Education and Research (BMBF) as part of the National Cluster of Excellence Medical Technology - Medical Valley EMN (Project grant No. 01EX1013B). On behalf of the ProHTA Research Group. The research within the domain of energy has been partially performed as part of the "Energie Campus Nürnberg" and supported by funding through the "Aufbruch Bayern (Bavaria on the move)" initiative of the state of Bavaria. Peter Bazan is also a member of "Energie Campus Nürnberg", Fürther Str. 250, 90429 Nürnberg.

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