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Towards model component reuse for the design of simulation models – a case study for ICZM

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Abstract: By itself scientific specialization does not serve the needs for integrated analysis of environmental problems required to improve the linkage between science and management. Models are often very case dependent, and lack the flexibility for rapid adaptation to new or different management or policy issues. The goal of the EU-FP6 research program SPICOSA is to develop a Systems Approach Framework (SAF) for Integrated Coastal Zone management. The project uses a modeling platform based on the integration of the dynamic simulation software ExtendSim and GIS software PCRaster. The approach is supported by model libraries in which reusable Model Building Blocks (MBBs) can be stored. The goal is to design these model components in a way allowing for reusability to design new simulation models for a different problem context from scratch. Such plug-and-play model library has several advantages: models are easier to build, adapt and maintain, but designing reusable MBBs for environmental modeling is not a straightforward task. Well-designed MBBs should be complementary to each other, self-explaining, encapsulated, robust, and meet the scientific standards. In addition, data management and the spatial dimension should be taken into consideration. The presentation will focus on the design principles of reusable MBBs and will provide some examples to explain the typical design issues and appropriate solutions.

Keywords: simulation, component-based design, model library, reusability, systems analysis

1. INTRODUCTION

Funded by the European Commission as an integrated project under the 6th framework program the *SPICOSA* project (www.spicosa.eu) aims to study the interaction between natural and socioeconomic processes that take place in Europe's coastal zones by adopting a **S**ystems **A**pproach **F**ramework **(SAF)**. *SPICOSA* stands for **S**cience and **P**olicy **I**ntegration for **CO**astal **S**ystem **A**ssessment. The general goal is to develop a self-evolving, holistic research approach and support tools for the assessment of policy options for sustainable management through a balanced consideration of the ecological, social and economic aspects of coastal zone systems. Typical policy issues that are under study in the project are the socioeconomic problems arising from increased nutrient supplies to coastal zone waters or the management of sustainable aquaculture in relation to freshwater supply and marine pollution. The project has a duration of four years and will last until February 2011. A key outcome of the project is a library of reusable model building components to standardize and facilitate the design and implementation of new, dedicated simulation models for addressing coastal zone management problems in the coastal areas of Europe. Such a component-based or "plug-and-play" approach for simulation modeling has several advantages. New models are easier to design and existing ones easier to modify, models become more transparent and easier to maintain, and scientific knowledge is easier to exchange and apply to different cases. Component-based design is the current-day standard in manufacturing and software engineering but few environmental modelling studies rely on reusable Model Building Blocks or MBBs. The APES framework for agricultural management (www.apesimulator.org) is an example of a component-based simulation environment. Due to its pan-European scale SPICOSA provides an excellent learning environment for examining the typical challenges and pitfalls of component-based design of multidisciplinary, environmental simulation models. All 18 SPICOSA case studies use the ExtendSim® simulation environment (ImagineThat, 2002; Krahl, 2002) to design, run, and test their coastal system models. In ExtendSim simulation models are constructed with standard library-based iconic blocks. In addition modelers can develop their own customized blocks and libraries. Each block describes a specific calculation or a step in a process, and is characterized by its in- and outgoing connectors, a user dialog and self documentation. An example is a block describing the temperature-dependent impact of light on phytoplankton growth. This paper takes the experience of SPICOSA to reflect on the pitfalls of designing reusable model building components and some actions to avoid these.

2. REUSABLE MODEL BUILDING COMPONENTS

The topic of reusable model building blocks for designing environmental simulation models receives more and more attention (Rizzoli et al., 1998; Daum, 1999; Argent, 2005; Papajorgji, 2005; Valentin and Verbraeck, 2002; Donatelli and Rizzoli, 2008; Verbraeck and Valentin, 2008). A model library allows models to be shared and (ex)changed in a modular fashion. Donatelli and Rizzoli [2008] emphasized the importance of framework independence of reusable model components and proposed a design approach based on component structure, interaction and quality. The design and population of a model library based on the outcomes of an ongoing project like SPICOSA is not straightforward. First of all, it is important to understand why a specific model block is reusable or not. Much of the success of component-based modelling depends on the quality and interoperability of the MBB's. For SPICOSA the following requirements were formulated and communicated to the project participants (De Kok and Maes, 2009):

- reusable for new simulation models
- complementary like jigsaw puzzle pieces
- self-explaining and well documented (not only in a report)
- encapsulated, i.e. the implementation can be hidden
- easy to adapt, expand and maintain
- manageable in size
- robust and reliable (i.e. tested for e.g. foolproofness)
- scientifically correct and matured

One of the experiences of the project is that most scientists, in particular junior researchers, have great difficulty deriving reusable components from their models that can meet these requirements (see Section 4 for more details). In SPICOSA each system model consists of several sub models which are hierarchically structured around model components that allow better interpretation of the model (Figure 1).

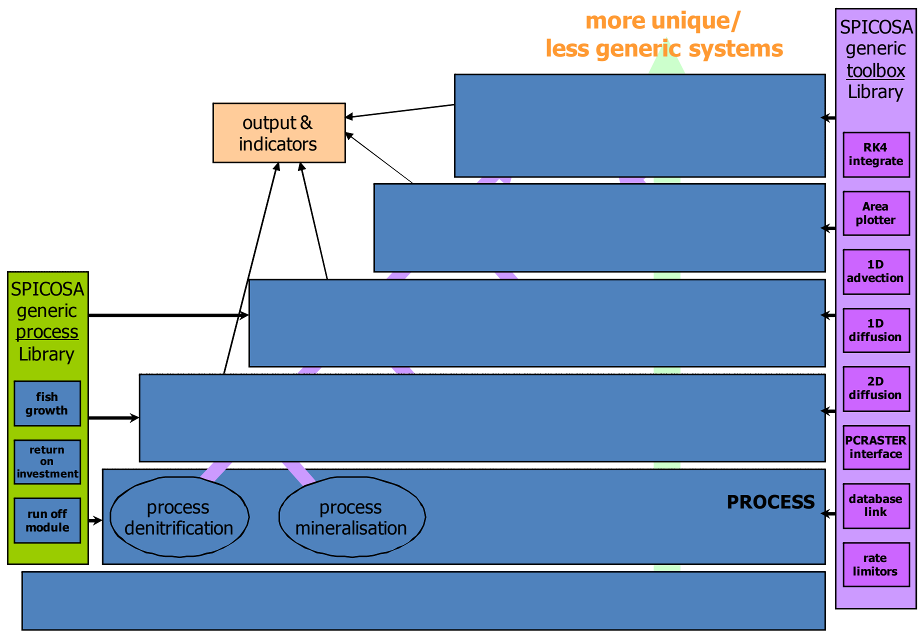

Figure 1. A framework for model block and hierarchical model design in SPICOSA.

Some applications require the explicit spatial representation of processes. An example is the effect of the distribution of waste-water treatment facilities on the estuarine water quality. For this reason an interface was designed to link the dynamic simulation models in ExtendSim with PCRaster, a raster modelling environment (http://pcraster.geo.uu.nl). It includes sophisticated raster GIS functionality emphasizing on analytical capabilities. PCRaster uses a scripting language for constructing models describing processes through time. These dynamic simulation models can easily be constructed using the rich set of model building blocks and functions found in PCRaster (Van Deursen, 1995).

3. DESIGN AND ORGANIZATION OF THE MODEL LIBRARY

The reusable MBBs can either be designed as hierarchical blocks based on the standard graphical icon blocks provided in ExtendSim, or coded in ModL, the C-type modeling language available in ExtendSim. Although these MBBs are functionally dependent on the ExtendSim simulation framework the latter type of MMBs are easier to transfer to other simulation frameworks. To standardize the layout of the MBBs for the model library and ensure a satisfactory level of documentation the study sites have been provided with standardized model block templates (Figure 2).

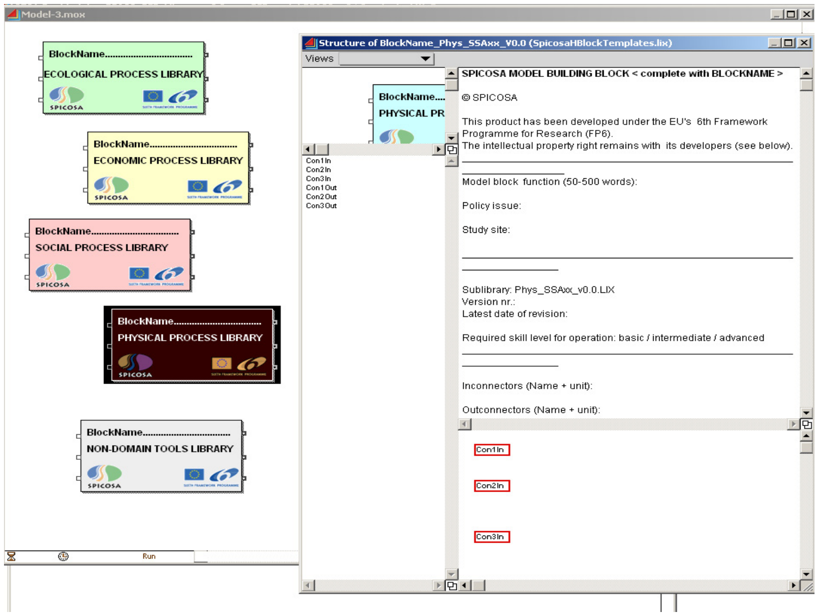

Figure 2. Model documentation pane of a SPICOSA template block.

In view of the scale and complexity of the project and the number and diversity of the deliveries to the model library, some additional measures were taken to ensure that the contents of the library will remain manageable and transparent for future users. First, the study sites were instructed to categorize their reusable MBBs in five categories, which are reflected by the templates: ecology, economics, physics, social processes, and a remainder category for non-domain oriented tools. Second, clear labelling and version number instructions were issued for all models, library files, and MBBs. For example, the name of each MBB is to indicate its functionality, the study site and version number. At a lower level similar instructions were given for the labelling of the connectors used to link the MBBs. A step-wise approach was recommended to guide the researchers with the design of their MBBs (Figure 3).

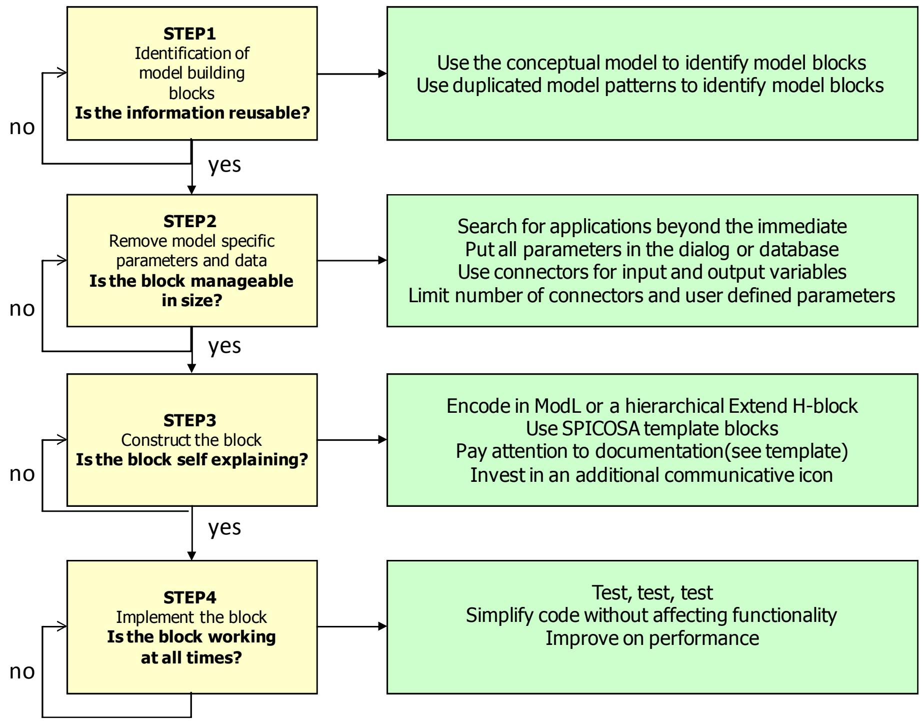

Figure 3. General procedure for deriving the reusable model blocks from the simulation models.

A separate work package in the project is responsible for the design and implementation of a model portal to be used for the storage, maintenance and exchange of both complete ExtendSim models as well as model libraries during and after the project (Figure 4). It can be used to up- and download models and model libraries, and search for specific model blocks depending on the requirements for its intended application.

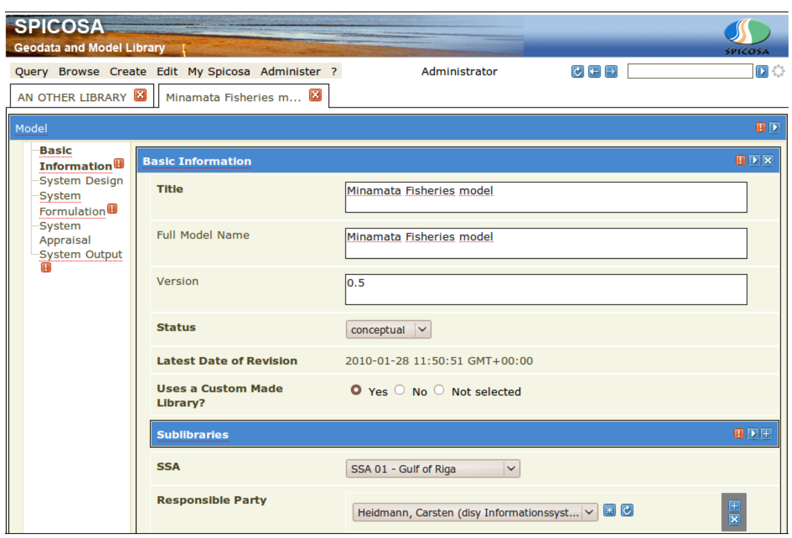

Figure 4. The online model portal.

An organizational aspect of the design of the MMBs is that a bottom-up approach was followed, i.e. the blocks were extracted after construction of the system models. This has the advantage that the scientific experience gained with the case study applications could be used to the benefit of the MBBs. The drawback, however, is that the scientific content of the case applications limited the range of MBBs to be designed. Therefore, the model library can be improved in terms of completeness and complementarity of the MBBs.

4. PITFALLS AND CHALLENGES

Verbraeck and Valentin [2008] point out several potential problems with the use of a model library for constructing new models such as a limitation of the modelling scope, a lack of confidence in the MBBs, and wrong use of MBBs due to a lack of understanding of their applicability. In SPICOSA most effort has thus far been spent on familiarizing the modelers with the concept of knowledge reusability and providing guidelines and tools to facilitate the design of reusable model building components. In principle, the scale of SPICOSA should ensure a balance of the library components over the broad range of disciplines from marine ecology, pollutant transport and cost-benefit analysis to stakeholder participation concepts. Nevertheless, the social sciences and economics are less well represented in the work of the study sites, which will without doubt affect the consistency of the prototype model library. This in turn limits the applicability of the library contents to new problems or case studies. In SPICOSA the problem was addressed by means of a tentative list of model building blocks to obtain an overview of the missing or overlapping functionalities. The list helped avoiding overlapping functionalities and identifying key elements that were to be given a high priority. Another problem is inter-block consistency. When deciding on the in- and out-going connections the developers of a reusable model building block need to be aware of the operation of their block when linked to other model blocks, which may pertain to a scientific domain that is not theirs. This is a basic aspect of integrated systems modeling, but can be challenging as most researchers still take their education in a single domain. A general observation is that the focus of the project lies with quantitative simulation modeling, although the problem formulation and system conceptualization have explicitly been included in the design of the project. This raises the question to what extent qualitative concepts to describe processes, like for example stakeholder consensus, can be captured in a reusable MBB. An interesting technique that could be explored to clarify the underlying mechanisms behind a problem is that of conceptual mapping. Extracting reusable components from a model raised also less fundamental problems like that of the management of the data used by the model block. It was decided to make a distinction between three categories of data:

1. General constants and fixed parameters; these could be stored inside the block with the requirement to list them in the documentation of the block

2. User-defined parameters; for these dialogue boxes were designed to accompany the MBBs and present them in a more transparent manner

3. Medium and large-scale sets of data used by the blocks (as a rule of thumb exceeding more then 10 values); these were stored in ExtendSim databases. The name of the database could be set in the user dialogue, whereas the database itself should be included in the example model build illustrating the MBB.

Furthermore, some models were fine tuned during the calibration step, with model parameters that were strongly case specific and model output that was highly sensitive for changes in the value of these parameters. Taking a component out of its model context could easily lead to abuse of the block and unrealistic model behavior. To avoid this the MBB developers were advised to limit parameter ranges, document their model blocks very carefully and set up a sample model for the blocks. These sample models were also used on several occasions to clarify the principles of reusable model building components to the project teams. Other difficulties could be attributed to the heterogeneity in model structuring, layout, and documentation. This hampered the identification of library material and was expected to result in considerable quality differences of the contributions to the model library by the different study sites. For this reason model block templates were developed and clear labeling and version number instructions were issued for the MBBs and library files.

5. CONCLUSIONS AND RECOMMENDATIONS

A bottom-up approach for the design of reusable model building blocks, based on existing simulation models, is more practical and can take advantage of the experience gained with the design of the integrated model. The drawback is that the scientific focus of the simulation studies will determine the scope of the model library. However, this can be expected to become less of a problem when (virtual) research communities start to exchange their model libraries more actively, which is one of the reasons for setting up the SPICOSA online model portal. Although the advantages of component-based design of environmental simulation models and model libraries of reusable components are clear to them, most scientists find it difficult to design model building blocks that meet the design criteria. Pre-constructed model block templates, tutorial blocks, and clear guidelines for a stepwise design of reusable MBBs can help overcome this problem. To ensure the robustness of the MBBs tests should not only be carried by means of plug-and-play replacement in the original simulation model, but need to be conducted also for new test applications. An inventory of potential candidate blocks for a model library can help avoid overlapping functionalities. On the other hand, the envisaged model library should leave room for different model concepts, even if these are closely related. To widen the support for component-based environmental modeling among the scientific community and facilitate the communication with end-users and stakeholders future work should also be aimed at developing tutorials and tools to make models more transparent and easier to control, improvement of the library completeness and inter-block consistency, testing blocks and setting up example applications which are scientifically convincing. The remainder of the SPICOSA project will be aimed at improving the quality of the model building blocks and complementing the library functionalities. The research consortium of the project, which includes over 50 institutes, provides a good starting point for this.

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