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Reusability of model components for environmental simulation – Case studies for integrated coastal zone management

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ABSTRACT

Model constructs in environmental models are seldom reused beyond the project lifetime or in other modelling studies. A library of reusable model components could facilitate the maintenance of existing models and make the design of new models more efficient. Although component-based design is the common standard in software engineering and manufacturing few examples are yet found in environmental science. The multi-disciplinary project SPICOSA used a common, component-based simulation framework for environmental modelling, based on 18 case studies through Europe. The development of high-quality model components with potential for reuse turned out to be a challenge despite of the guidelines and tutorial examples provided. Well-designed components are of appropriate granularity, encapsulated, with a limited use of connectors and proper data handling. Ultimately, the success of a model library depends on a sufficient set of quality components with complementary functionalities, a framework for quality control, and support of the environmental modelling community.

Software availability

Software: ExtendSim® Windows version 7.06, Continuous Process (CP) Base Package
Model Library: http://dataportals.pangaea.de/spicosa/SPICOSA_model_library.html

1. Introduction

An increasing number of environmental projects rely on simulation models to make scientific knowledge available for integrated environmental management (Van Ittersum et al., 2008; Hopkins et al., 2011; Laniak et al., 2013). Despite the effort spent on designing, implementing, calibrating and validating models, the ease of maintenance and post-project exchange or improvement of model constructs rarely receives attention during modelling projects. Component-based design has become the common standard in manufacturing and software engineering (Brown, 1999; Chiang, 2003) and environmental researchers increasingly acknowledge the benefits of component-based modelling (Rizzoli et al., 1998; Daum and Sargent, 1999; Engelen, 2003; Argent, 2004; Papajorgji et al., 2004; Voinov et al., 2004; Argent, 2005; Donatelli et al., 2007; Donatelli and Rizzoli, 2008; Rizzoli et al., 2008; Verbraeck and Valentin, 2008; Villa, 2009; Castronova and Goodall, 2010; Holzworth et al., 2010; Verweij et al., 2010; Valentin, 2011; Laniak et al., 2013; Škerjanec et al., 2014; Whelan et al., 2014). Nevertheless, the design of reusable model components still poses a challenge to the majority of environmental modellers and is not their first priority. As Laniak et al. (2013) point out there exist to date no general guidelines or formal standards to support the functional design of reusable model components. Conceptual and scientific difficulties related to the design of model components are generally solved implicitly by the teams constructing integrated models. In other words: it is still an art to make model constructs reusable. Recommendations made to address the problem include the application of object-oriented approaches, hierarchical design, and ontologies to represent and exchange scientific knowledge, including a model design based on reusable components (Argent, 2004; Rizzoli et al., 2008; Castronova and Goodall, 2010; Holzworth et al., 2010; Verweij et al., 2010; Laniak et al., 2013).

Abbreviations: DLL, Dynamic Link Library; GMP, Good Modelling Practice; H Block, Hierarchy Block; SAF, Systems Approach Framework; SPICOSA, Science Policy Interface for COastal System Assessment; SSA, Study Site Application.

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The central goal of the EU-FP6 program SPICOSA (www.spicosa.eu) was to design, implement and validate a Systems Approach Framework (SAF) for sustainable development in coastal zones, based on 18 case studies in as many countries (Hopkins et al., 2011). The SAF methodology is characterized by strong end-user participation, an open, iterative modelling process, and systems modelling with feedback. The first priority for the modelling teams was with the SAF approach and design of their simulation models. The design and testing of model components with potential for reuse was a secondary objective. ExtendSim® (ImagineThat, 2007; Krahl, 2002) was chosen as common modelling platform.

Here a model component is understood to be a self-contained model construct, typically describing a specific process at the level of system state variables. An implicit objective of SPICOSA was to develop and test model components for a generic model library to support component reuse and quality control (Fig. 1).

The combination of a common modelling environment and wideness of applications and modelling domains in SPICOSA form an interesting testing ground for the design and reuse of model components. A number of problems could be observed with respect to the subtask of developing reusable model components. Although the advantages of a generic library of reusable components were explained early on in the project and generally acknowledged, little effort was spent on the design of components to simplify the model structure and exchange model constructs between the case studies. The components that were delivered by the end of the project suffered from a strong case dependency, excessive number of in- and outgoing connectors, lack of separation between data and process description, or documentation, all of which limit the reusability of these components. Here reusability refers to an appropriate combination of flexibility, granularity (the level of detail), user-friendliness and transparency, which makes a model component reusable in other models, and facilitates the design and maintenance of existing models. A large variability could be observed in the model architecture and use of components, ranging from models that were organized around a few, overly complex components to models of high granularity, resulting in a complex network of inter-component connections.

The objective of this paper is to use the experience of SPICOSA to analyse the challenges and potential solutions with respect to the design of reusable model components. In Section 2 we discuss the design principles of reusable model components. Next, we briefly introduce the common software framework used in SPICOSA, the component reuse patterns observed, and the guidelines and support provided to the modellers to assist them with the design of their models and components, including an example of a well-designed, reusable model component. This is followed by a general comparison of the models to analyse the differences in component use and reuse, and an evaluation of the compliance to the design guidelines. In Section 5 we analyse two example applications of a model component in more detail to identify the specific difficulties which could affect the reusability. The paper is concluded with a discussion of the challenges of component-based modelling and lessons to be drawn from SPICOSA with respect to the design of reusable model components.

2. Background

2.1. SPICOSA

Integrated Assessment Modelling or IAM (Parker et al., 2002) is generally considered useful to analyse complex environmental problems and support policy making with scientific knowledge. Increasingly the EU relies on the outcomes of such models to underpin new policies (Ewert et al., 2009). The majority of IA models are still case specific, and little attention is paid to the generic application and flexibility of these models (Ewert et al., 2009). More and more, IAM is seen as a participatory activity in which stakeholders, decision makers and scientists work together to identify the problems, define the system to be modelled including the feedback structure, develop scenarios describing the context of the system, select indicators to evaluate and compare different management actions (Ewert et al., 2009; Janssen et al., 2009), and validate the model behaviour. All-in-all the SPICOSA project can be considered to be a challenging exercise in integrated assessment, system simulation, and participatory and component-based modelling. Eighteen different case studies were selected to explore and test the SAF methodology. The expertise of the researchers ranged from little to no modelling experience to extensive expertise in the use and design of complex environmental models, including spatially-dynamic simulation related to e.g. hydrology, land-use change, ecology and integrated assessment. The partially overlapping study themes included coastal eutrophication, pollutant transport, shell species farming, fisheries, agriculture and water quality, pollutant abatement, and beach attractiveness. A technical model support work package assisted the study teams with the design and improvement of their models, and coordinated the delivery of reusable components by the end of the project. This was done by regular evaluation of the models and components, the design of technical components to support the modelling process upon request, and the formulation of component and model design guidelines.

2.2. Component-based modelling

The technical and software engineering aspects of component-based modelling receive more and more attention in the international literature (Papajorgji et al., 2004; Argent, 2005; Rizzoli et al.,

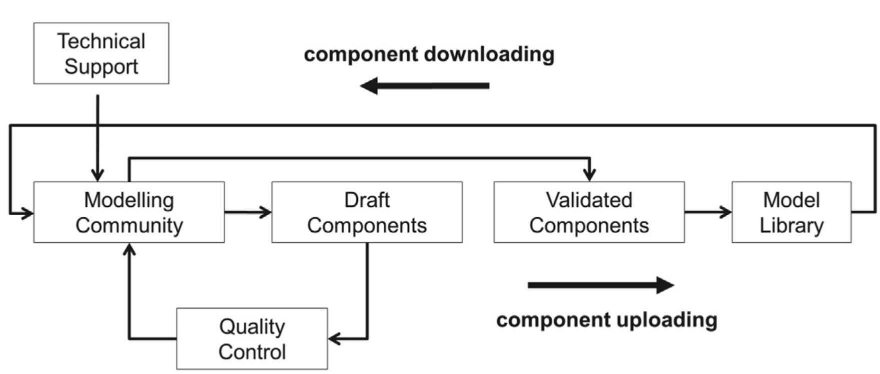

Fig. 1. Open source paradigm for quality control and exchange of model components in a generic component library.