LINKING AND REUSING MODEL COMPONENTS FOR ENVIRONMENTAL SIMULATION

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Abstract: Simulation modelling is widely accepted as a tool to gain understanding of the behavior of environmental systems under pressure and support their integrated management. A common practice is that the modelling process is aimed at identifying the relevant problems and potential management strategies in close coordination with stakeholders before translating the available domain expertise into integrated simulation models. The challenges include the need for cross-disciplinary thinking and model linking, incorporation of social science knowledge, and the communication aspects of projects. Most projects bring along their own case studies, with simulation models being designed from scratch. Although component-based design is the common practice in software engineering few examples are found in environmental modelling. Project deliverables are often not reused by parties different from those that developed them. An open-source library of well-designed, reusable model building components could pave the way for a more efficient use of modelling resources and considerably improve the efficiency and flexibility of the modelling process, thereby creating more room for the communication with end users, scientific discussions, and model interface design. The experiences of a multi-disciplinary simulation study of coastal systems are used to discuss the methodological aspects and pitfalls of the design of reusable model components.

1 INTRODUCTION

Environmental systems are under increasing man-induced pressure and the response to different external conditions and combinations of management options depends on the complex interactions between the social, ecological and economic processes involved. Different integrated simulation models have been developed in the past to support strategic environmental planning. Unfortunately, these models are often not reused by research groups other than those that developed the models. One of the more important reasons is that the degree of reusability of model constructs is limited due to the specific requirements of the modelling framework used (Rizzoli et al., 2008). Reusability and flexibility for application by third parties is seldom a priority for domain experts, who often lack the professional software engineering skills needed to make their products easily transferable. Well-designed, reusable components representing key functionalities could facilitate the exchange of scientific expertise between environmenttal modellers across different modelling domains. In turn this would allow for a more rapid and efficient design of new and maintenance of existing simulation models. Multi-disciplinary simulation studies with a policy-supporting objective could benefit from a generic library of reusable components because it reduces the effort required from generalist modellers for the design of integrated simulation models (Donatelli et al., 2008). In turn this will leave more room for the communication with stakeholders and addressing scientific issues. The advantages and challenges of a component-based design process for simulation modelling is a topic of growing interest (Argent, 2004; Papajorgji, 2005; Rizzoli et al., 2008; Verbraeck and Valentin, 2008). The aim of a recently concluded research project SPICOSA (www.spicosa.eu) was to develop a methodology for science-policy interfacing in the field of integrated coastal zone management. The scale and integrated nature of the project, need to exchange model fragments, range of different research themes and component-based modelling platform used made the project an interesting testing ground for the concept of reusable model components (De Kok et al., 2010).

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The project was organized around the different design phases of integrated simulation models linking the ecological, economic and social aspects to the promising management strategies. Regular consultations with stakeholders and representatives of coastal planning institutes formed a key aspect of the project. The modelled themes ranged from fisheries and shell-fish farming to beach attractiveness and coastal and inland eutrophication. ExtendSim® (www.extendsim.com) served as common simulation platform to allow for easy exchange of model constructs between the different project teams. This modelling environment supports the component-based, hierarchical design of dynamic simulation models to describe discrete and continuous systems. Drag-and-drop linking of reusable model components which are stored in different libraries makes the design and maintenance of models relatively easy, even for less-experienced modellers. In addition, a large number of tools are available to customize and improve the layout and control of the model, an advantage in projects developing policy instruments to be used in interactive sessions with stakeholders. Simulation models can be designed and modified by linking standard components based on graphical icons, or by means of more powerful coding in ModL, a programming language similar to C (Fig. 1). Modellers can also reorganize their components in custom libraries to support the exchange of model constructs. The project teams were required to contribute one or more reusable model building components to a generic model library, an important deliverable of the project. Typical design criteria for model components are reusability, flexibility, encapsulation, interoperability (Papajorgji, 2005; Rizzoli et al., 2008; Verbraeck and Valentin, 2008) as well as framework independence (Rizzoli et al., 2008). General guidelines for the design of components were issued in the project (De Kok et al., 2010) to help the modellers with their task and ensure a certain degree of reusability of the delivered components. The practical implementation of the design guidelines turned out to be less straightforward than expected, and some interesting lessons can be drawn from the project. Here we take a few examples of component linking and reuse to reflect on the scientific and technical difficulties.

2 DESIGN APPROACH

The majority of environmental modellers are less familiar with component-based design, because it is not their first priority. The common practice is that models expand gradually and iteratively in terms of the functionalities included while gaining in complexity. Frequent problems with the early deliveries to the model library in this project included a lack of separation of models and data, excessive and inappropriate use of connectors, overcomplexity, inadequate documentation and testing, and functionalities that were too much dependent on the case study modelled. The advantages and general principles of component-based modelling therefore had to be clarified by means of tutorial examples taken from different application domains. A literature review of the design criteria that were mentioned earlier formed the starting point for a number of more concrete, project-focused guidelines and templates to standardize the design process and avoid the common pitfalls. Domain-independent components with functionalities related to up- and downscaling, user dialogues, im- and export of data, encryption, statistics etc. were developed to support the project teams with the design and polishing of their simulation models. For organizational reasons the majority of the components were designed by means of a top-down procedure, and derived from the simulation models at a late stage in the project. The advantage of this approach is that the modelling experience and data needed for the calibration of the components were available, and the priorities were clearer. On the other hand, the design of the simulation models could not fully benefit from the component-based design approach, compared to a bottom-up approach.

Repeated exchanges to obtain feedback from the support team and more experienced modellers helped the project teams with the polishing and improvement of their components. The approach for designing the model components addressed the following aspects:

1. First, it was necessary to identify which *functionalities* could be useful to others. Here, functionality is defined to be the modelled process with in- and outgoing state variables. An example is a component which describes the population dynamics of a fish stock, with the fishing effort as input and stock size as output variable. The mathematical and visualization tools available in the standard ExtendSim® libraries are typical examples of components with a high degree of reusability, but pertain to a low level of model detail. More complex and process oriented components were needed to reduce the effort required for developing a new simulation model. On the other hand, components

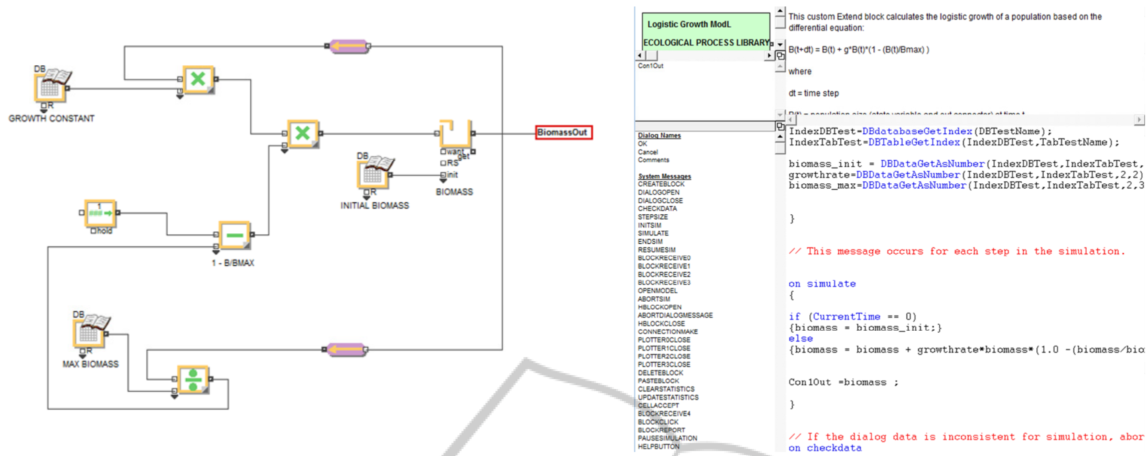

Figure 1: Icon-based (left) and ModL coded (right) component for logistic population growth.

which are too complex and case-dependent can be expected to be less useful for application in other modelling studies. Choosing the appropriate level of detail, also referred to as the *granularity* (Donatelli et al., 2008) of a component is essential. Screening resulted in a tentative list of over 80 candidate components pertaining to different model domains and levels of detail. These components were classified in five subcategories: ecological, economic, social, physical, and domain-independent support components. Fig. 2 shows an example of a phytoplankton dynamics component from the ecological sublibrary.

2. The technical implementation was relatively straightforward once the functionality of a component had been specified, using the supporting graphical tools available in ExtendSim®. The next step was then to *restructure* the component and remove redundant connectors and model-specific parameters as much as possible, which would otherwise impede the connection to components with complementary functionalities. The use of in- and outgoing connectors was strictly limited to state variables, whereas model-specific parameters and input data were stored in databases or set in user dialogues. The use of global arrays to store and exchange model parameters was also discouraged to in order to reduce the model dependence. Instead the general recommendation made was to separate the model code as much as possible from the data, use generic indexing of database records, and add transparent user dialogs to pass case-specific model parameters. Some components were extended with control options to create or access databases on user demand, thereby increasing the level of flexibility.

3. After restructuring of each component the design process focused on the *layout and documentation*. Standardized templates were developed to ensure a certain degree of uniformity and proper description of the functionality, scientific background, application domain, and references to the developers. The use of simplified demonstration applications with sample input was encouraged in order to clarify the use of a component to other modellers.

4. Next, the project teams were asked to verify and test their components, to ensure the *reliability*, a prerequisite for use by others. The components were extracted from the supportive library and preferably pasted into a blank model worksheet to test the functionality with different sets of input variables, whereas model-specific parameters were restricted to their physical range. These tests included component linking if possible and meaningful.

5. The general recommendation was to focus on the *genericity* and *reusability* of the components for other applications and modellers. Components were reused within and between simulation models and frequently exchanged among the modellers. A proper component should allow for changes in use, such as the number of fish species. Two other design criteria were equally important but more difficult to achieve. Although the *interoperability* of components has been addressed in the past (Chiang, 2003) this important design criterion received only limited attention in the project because most of the simulation models were used to derive components rather than the other way around. Moreover, the majority of the study teams delivered only a few components related to the processes modelled in their case study. Nevertheless, the study sites were asked to limit the number of in- and outgoing connectors and reserve these for the key state

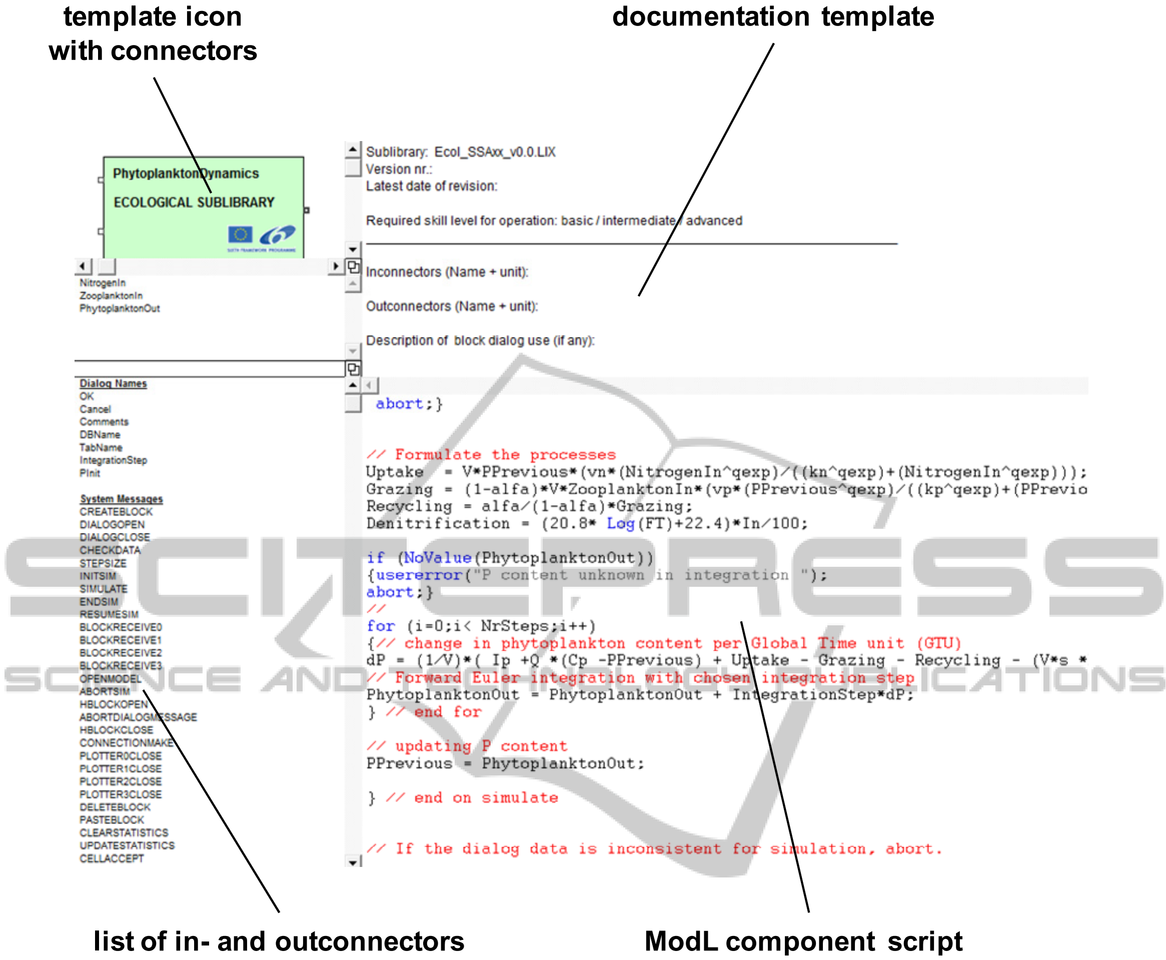

Figure 2: Component for phytoplankton dynamics.

variables to improve the interoperability of their components. The *complementarity* of the components was limited by the modelled domains and processes, with insufficient contributions from the social and economic sciences to fully meet the demands for supporting ICZM. The expectation is that this imbalance will gradually improve once a wider community of modellers starts using the model portal.

3 APPLICATIONS

A total of over fifty reusable components had been delivered by the end of the project, with overlapping functionalities and a general focus on physical and ecological functionalities such as light extinction and algal development. ExtendSim® can automatically assign a global simulation order to all components in a model. This can cause problems after replacing components passing information at distinct time steps in a hierarchically organized model. The problem was solved by setting the simulation order manually. To avoid these problems such reusable components should verify the proper and timely passing and initialization of variables. A tutorial model of complementary components from different sublibraries was developed to demonstrate the advantages of component-based modelling for an intermediate review of the project (Fig. 3). The simulation model links plankton dynamics to shell species growth and the income from harvesting. Adding and linking components, completing the user dialogues, and importing the databases takes only a few minutes for this model. Because the components are taken from different sublibraries and case studies this example also demonstrates the complementarity and connectivity of the components.

Powerful database functionalities are available in ExtendSim® to drive the simulations, read model input and store model output. A general

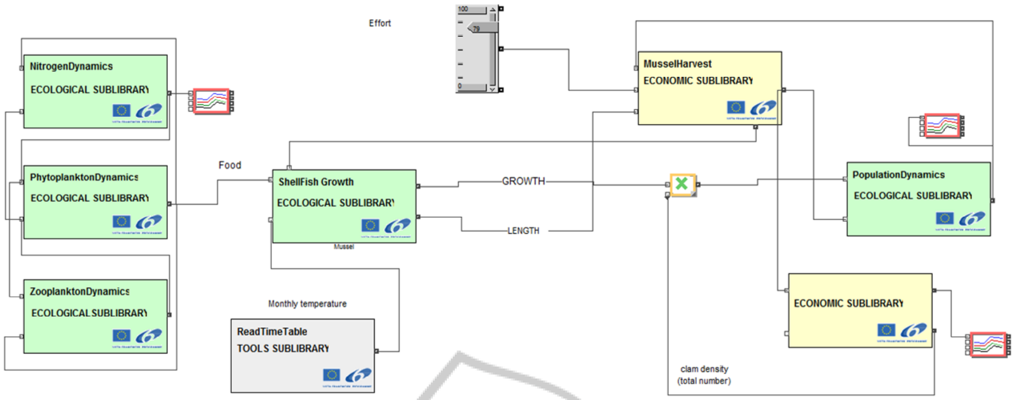

Figure 3: Demonstration model linking components from different sub libraries.

recommendation was to let the users of the model set the path and label input data files via the user dialog, rather than defining these in the component script internally. An example is a user dialog (Fig. 4), based on resizable tables with economic data and different options to create new or delete existing tables, with automatic testing of the size of arrays being im- or exported. The structure of the database tables automatically determine the number of economic sectors.

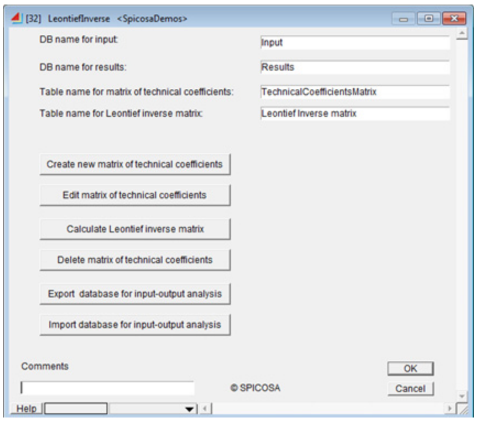

Figure 4: Tutorial example of linked components for economic input-output analysis and tourism demand.

4 CONCLUSIONS

Component-based simulation of environmental systems has considerable advantages: models are easier to design, restructure and maintain, and model constructs can be exchanged and combined more easily. The most important design criteria for reusable components for integrated environmental simulation are genericity, functional complementarity, proper documentation, reliability and modelling framework independence (Rizzoli et al., 2008; Verbraeck and Valentin, 2008). A web-based *model portal* was set up to support the future exchange, maintenance and documentation of the reusable components. This portal will be maintained after the project and a quality assessment of the deliveries is currently being made. The majority of the components delivered by the case studies pertained to ecological processes with less attention for social and economic applications. Some of the delivered components, such as those describing the population dynamics of fish stocks and shell species, still are to be recombined into more generic tools. A following step is then to gain wider support for the model portal to encourage future contributions, in particular those of the social sciences. Although the components developed in this project depend on a specific simulation platform the ModL coded components can be transferred to a different modelling framework, for example using enhanced interface semantics as proposed by Rizzoli et al. (2008) instead of the user dialogues and databases which are currently used. Wide acceptance by a community of domain experts depends on proper documentation and concrete tutorial applications of modelling tools targeting an audience including the less skilled simulation modellers. Although the simulation environment used in this project adequately supports component-based modelling it does not guarantee the reusability of components. Modellers should become aware of the consequences of reuse of their work in a different model context at an early stage of projects. The general lesson of the project is that the majority of researchers are still insufficiently familiar with the concept of modular design, although the advantages are generally understood. Tutorial examples and demonstration projects are not sufficient by themselves to pave the way for component-based modelling of (environmental) systems. Organizational and technical resources such as the web-based model portal will be needed to support the exchange, quality improvement and management of reusable model components. Whether the existing model portal should be generally accessible is a matter of discussion. The open-source concept seems to be the best way to ensure sufficient and adequate feedback on the contents of the model library, a necessity for quality improvement. Reclassification in functional categories and screening of existing simulation models will help identify missing components. A functional model library should not only include abstract, generic objects but also abundant concrete tools at a higher hierarchical level to ensure general acceptance among domain experts. Ultimately these efforts should lead to a gradually expanding library of reusable model components representing processes from different domains, including those of the economic and social sciences, to meet the demands of all potential users.

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