MANAGING MATHEMATICAL MODELLING BY GUIDING AND MONITORING

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Abstract

Multidisciplinary model-based problem solving for water management is a complex process. Projects that have to follow this process may encounter many problems, related to miscommunication, malpractice, misuse of the model, insufficient knowledge of the problems modeled and overselling of model capabilities. This leads to model project, which is not transparent and difficult to audit.

The knowledge based system (KBS) discussed in this chapter provides guidelines on what to do, derived from an ontological knowledge base (KB), which contains state-of-the-art knowledge on 'best modelling practice' for teams of which its members have different disciplinary backgrounds and play different roles in a project. Furthermore, the KBS monitors what each team member actually does and helps generating project reports for various audiences and purposes. The last component of the KBS consists of multimedia training material helping novice users to find their way in the KBS.

The developers of this KBS learned that arriving at consensus on a process KB (here for model-based water management) has an intrinsic value. Professional users tested the KBS in two series of ten test cases. They like it and their comments have significantly improved the KBS. But they also expect that it will be hard to persuade large parts of the professional modelling community to using it in their daily practice. Students found it complex and cumbersome, but the quality of their modelling work increased.

Keywords: mathematical model, multidisciplinary knowledge, ontological knowledge base, modelling support, water management.

Background

Context

Mathematical models have been applied for several decades to support model-based problem solving for decision-making, including water management. Recent developments, e.g. an integrated problem-solving approach with awareness of socio-economics aspects in water management and environmental modelling, set higher demands to quality assurance for model-based problem solving.

Problem

The growing interest for quality assurance is fuelled by a multitude of reasons, including ambiguous terminology, a lack of mutual understanding between key-players, malpractice in regard to input data, inadequate model set-up, insufficient calibration/validation, model use outside of its scope, insufficient knowledge on some processes, miscommunication of the modeller to the end-user, overselling of model capabilities, confusion on how to use model results in decision making and a lack of documentation and transparency of the modelling process.

The responses of the modelling community to these problems consist mainly of guidelines, but these are usually nationally based and focused on single domains/disciplines (BDMF, 2000, Middlemis, 2000, Van Waveren *et al*., 1999, Scholten, 1999, 2000, Scholten *et al*., 2000, 2001). Resulting model outcomes and decisions based on them are often non-transparent, irreproducible, non-auditable and not fully comparable among different countries.

An additional complicating factor is related to the changing character of model-based problem projects from monodisciplinary, single person and academic oriented research model studies to multidisciplinary, decision support oriented projects, in which teams consisting of members with different background and different roles co-operate to complete the complex job. Modelling in multidisciplinary modelling teams facilitates exploring more complex questions, but it also makes co-operation in teams more difficult. Team members with different scientific backgrounds encounter more communication problems, which makes managing multidisciplinary model-based water management projects a cumbersome affair.

In an EC funded project, HarmoniQuA, a knowledge based modelling support tool has been developed to lower many of the hurdles encountered in present simulation modelling.

Learning Objectives:

- Multidisciplinary projects are instances of processes in which multidisciplinary teams have to cooperate.
- Completing multidisciplinary projects can be supported by a knowledge-based system (KBS).
- Throughout the lifecycle of a project team members get guidance on what they have to do customized for their disciplinary background and their role in a project.
- What team members actually do is monitored by the KBS, which makes the process transparent and enables auditing.
- The KBS helps teams to generate customised reports for various audiences and purposes.
- The KBS facilitates communication between team members and helps them to report what has been done, formatted for various purposes and audiences.
- For the case study in this chapter the knowledge base is filled with knowledge on model based problem solving in the context of water management.
- The knowledge-based technology (knowledge base structure and support tool) is re-useable for other types of mathematical modelling and other complex cooperation processes.

Approach

To facilitate the work of multidisciplinary teams in model-based water management the following approach has been followed. The mathematical modelling process has been decomposed in elements. Based on this decomposition and experiences with other processes an ontological knowledge base (KB) has been designed with levels of increasing specialization i.e. from rather abstract to describing modelling for water management in all details.

This KB and its editor are the backbone of the knowledge-based system (KBS), which further consists of the Modelling Support Tool (MoST) and training material. MoST filters relevant pieces of knowledge from the KB, depending on the disciplinary background and role of a team member and presents this knowledge in a structured way. Moreover, MoST monitors what all team members do and helps generating 'smart' reports for various audiences and purposes. The training material has been developed to make flatten the learning curve of the KBS for novice users. This training material consists of written material, presentations, exercises that encourage using MoST in a training test case project and many screen-recording movies on MoST, its knowledge base, a case study and some background information. The movies are the core part of the training material and aim at helping users to work with MoST and act as a sort of animated help facility.

The complexity of the KBS (KB, support tool, training material) sets high demands to the development process. Therefore, a three stage building process has been followed, interrupted by two functional test periods, in which the KBS has been tested.

Case Analysis

Knowledge Base

Development process

A combination of the definitions of Gruber (1993, 1995) and Borst (1997) leads to an operational definition emphasizing the negotiation aspects: *an ontology is a formal specification of a shared conceptualization*, referring to what can be represented in terms of concepts and the relationships among them

A small team consisting of persons responsible for the knowledge base (KB) has ontologically decomposed the modelling process in *concepts* and *relations* between these concepts in increasing levels of specialization (*level 0*: a bootstrapping terminology, *level 1*: a generic process ontology, *level 2*: a modelling process instance and *level 3*: specialized for water management). Subsequently, this decomposition has been used to design and implement ontology in Protégé2000 with the modelling knowledge as instances of this ontology, together forming the knowledge base. All details of the modelling knowledge for domains of water management have been uploaded to these instances. Within a larger group of professional modellers for water management, this knowledge base has been discussed in several rounds to achieve consensus, leading to a body of knowledge, shared by larger parts of the modelling community.

Ontological structure

An ontology can be seen as a framework to represent the structure and content of a body of knowledge on a domain in a formal machine processable way. In order to describe the structure and the content of knowledge, ontologies must have one or more standard vocabularies at hand, which define the terms (*concepts*) and *relations* between the terms to describe this specific knowledge domain (subject area). *Concepts* can be discussed and have to be represented. Concepts encompass abstract and concrete things, processes, tasks and ambitions or goals. *Concepts* are used to define and explain terms. *Relations* organize *concepts* in a hierarchical or in some self-defined structure. Often ontologies contain other elements e.g. *properties*, *functions*, *axioms*, but these are not essential to understand what ontologies are. *Instances* are also parts of an ontology, as they contain the actual knowledge. If *task* is a concept in an ontology, the instances of *task* can be *go shopping*, *cook a meal*, *eat the meal*. A comprehensive and clear introduction on what ontologies are and why we need them is given in Chandrasekaran *et al.* (1999).

Protégé2000 (Protégé, 2000) has been chosen as tool for the development of the ontological structure and for filling the KB with the collected knowledge. The latter has been archived as instances of the ontological structure. Developing two extensions has expanded the functionality of Protégé2000. Firstly, a plug-in for XML-export has been built, according to a predefined XML-format, interpretable for the KB and for the support tool that has to co-operate with the KB. Secondly, a web based front-end knowledge base editor has been built that allows the modelling experts without knowledge engineering skills to view and edit the contents of the knowledge base (Kassahun *et al.*, 2004), because even an easy and user-friendly tool like Protégé2000 could form an obstacle for experts in a specific knowledge domain that are not using knowledge engineering tools in their daily practice. The knowledge base editor reflects the Protégé2000 ontology developed for the modelling knowledge base. When the ontology changes the editor adjusts itself to the new ontology carrying along knowledge items into the new structure.

The knowledge base editor presents the knowledge in the KB as web forms. Domain experts can add, edit and delete KB content (i.e. the instances of the ontological structure) within their own field of expertise. This authorization mechanism of the knowledge editor minimizes conflicting updates and errors. Finally, the knowledge base editor provides all interested individuals the possibility of providing their comments and suggestions.

The KB distinguished three decomposition levels. At the highest level the modelling process has been divided into **steps**, which are groups of **tasks**. To perform a **task** one or more **activities** have to be carried out. **Activities** are associated with the role of a team member and are the smallest 'doings' in the process. A **task** is related to what has to be done and it refers therefore to the modelling process. By performing all its **activities** a **task** will be completed. **Steps** are logical groups of **task***s* and have only an organizational purpose for human actors involved in the process.

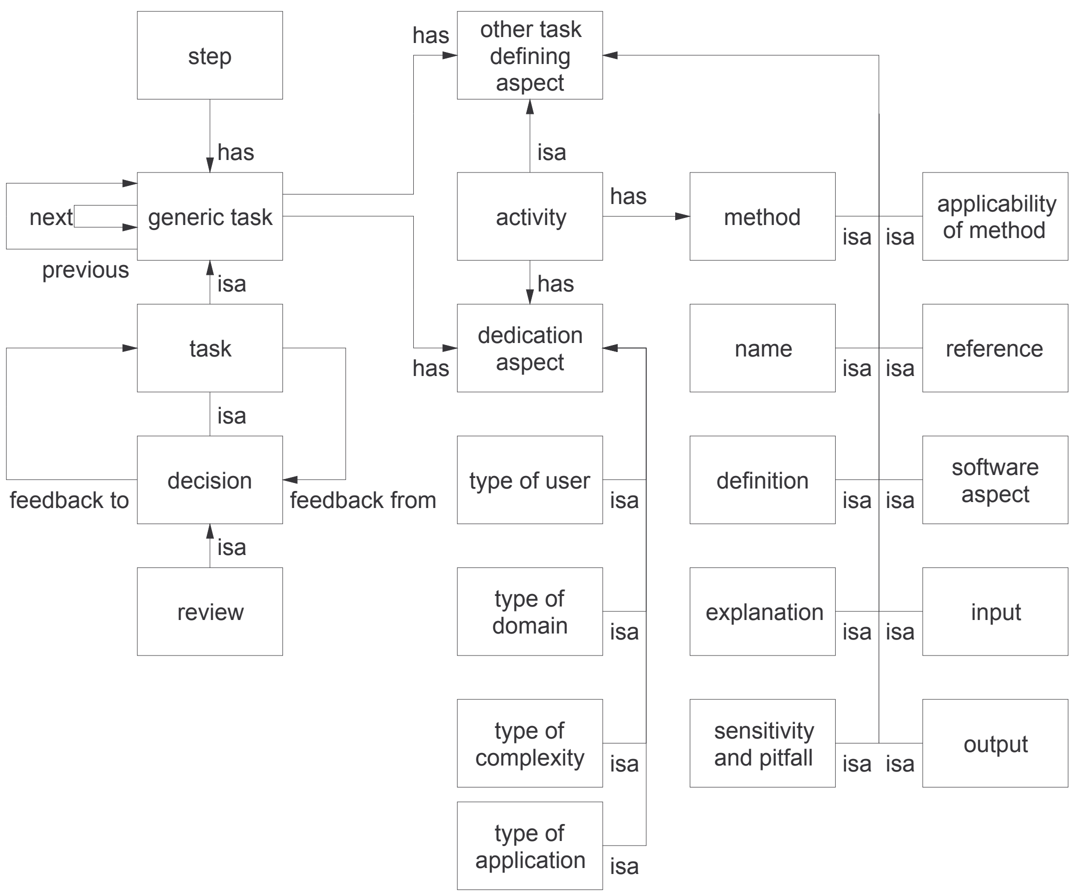

Figure 1. The ontological structure of the KB. Rectangles are concepts and arrows relations. The relation 'isa', means 'is a'.

The modelling process has been divided into 5 **steps** and at a lower decomposition level into 45 **tasks**. Each **task** was further decomposed in the following **task describing components**: **name**, **definition**, **explanation**, one or more **activities** (most with one or more associated **methods** and their **applicability**), **references**, **software aspects**, **links** to other tasks and **input** and **output** of that task. In the decomposition three types of **tasks** are distinguished: normal **tasks**, **decision tasks** (to decide on advancing to the next task or going back to a previous one) and **review tasks** (i.e. special **decision tasks** emphasizing the negotiating interaction between *water manager* (i.e. client) and *modeler*). Figure 1 presents the ontological structure used for the modelling knowledge base.

Modelling experts from each of the seven water management domains filled the KB by providing their expertise to each **task** and indicated the relevance for the user type and job complexity. The KB has been tested in several ways, which is discussed in section 'Testing'. Results of the tests have been used to change the KB structure and content, which appeared to be easy because of the ontological nature of the KB.

Furthermore, the domain experts delivered a prototype glossary of almost 1000 entries, which has also been included in the Protégé2000 KB. The glossary entries can be accessed from the guidelines presented by the support tool through hyperlinks.

Guidelines for model-based water management

The knowledge base is too large and complex to be discussed here in detail (see www.HarmoniQuA.org). See for some details Refsgaard *et al.* (2005). In the KB the modelling process is divided into the following **steps**: (1) MODEL STUDY PLAN, (2) DATA AND CONCEPTUALIZATION, (3) MODEL SET-UP, (4) CALIBRATION AND VALIDATION and (5) SIMULATION AND EVALUATION. **Steps** are decomposed into **tasks**. In the KB **tasks** belong to the work of one or more user types, i.e. roles that team members have in a modelling project. The following user types are included: *water manager*, *modeler*, *auditor*, *stakeholder* and *concerned members of the public*. The first **step** (MODEL STUDY PLAN) starts with three **tasks** for the *water manager*: DESCRIBE PROBLEM AND CONTEXT, DEFINE OBJECTIVE and IDENTIFY DATA AVAILABILITY. The *water manager* also has the main responsibility for the fourth **task**, DETERMINE REQUIREMENTS, but here the opinions of possible *stakeholders* and *concerned members of the public* on the overall objectives and context of the modelling study should be taken into account before it is all compiled in the fifth **task** PREPARE TERMS OF REFERENCE. In the sixth **task** (PROPOSAL AND TENDERING) there are roles for the *water manager*, the *modeler(s)* and the *auditor*. The seventh **task** in this **step** is the *decision* **task** AGREE ON MODEL STUDY PLAN AND BUDGET, where *water manager* and *modeler* have to discuss how the model study has to be continued. If the parties come to an agreement to continue, one has to carry on with the **step** DATA AND CONCEPTUALIZATION and do the next **task,** which is the first of the second **step** DESCRIBE SYSTEM AND DATA AVAILABILITY. This **task** is typically a *modeler's* **task** (Figure 2). If one decides in the *decision* **task** AGREE ON MODEL STUDY PLAN AND BUDGET to redo some of the previous **tasks**, one has to return to the **task** DEFINE OBJECTIVES. Figure 2 shows the first two decomposition levels of the modelling process.

After the first **step** MODEL STUDY PLAN the next **steps** consist mainly of **tasks** to be done by *modelers*, but each step concludes with a **review task**, in which other user types (*water manager*, *auditor*, *stakeholder* and *concerned members of the public*) participate.

The **tasks** briefly presented here do not consist of **activities**, which have complex **methods** to be used, as is for instance the case for the complex **task** UNCERTAINTY ANALYSIS OF SIMULATION in the **step** SIMULATION AND EVALUATION. This **task** consists of several **activities** to do and a number of **methods** to use. The guidelines for model-based water management describe several **methods** for this task. The user may select a **method** in order to comply with the requirements of the project. Users are not enforced to use one of these methods provided by the guidelines, but can also use other, more appropriate methods. The **methods** provided by the guidelines for this **task** include MONTE CARLO SIMULATION, SENSITIVITY ANALYSIS, REGRESSION TECHNIQUES, NUSAP, EXPERT

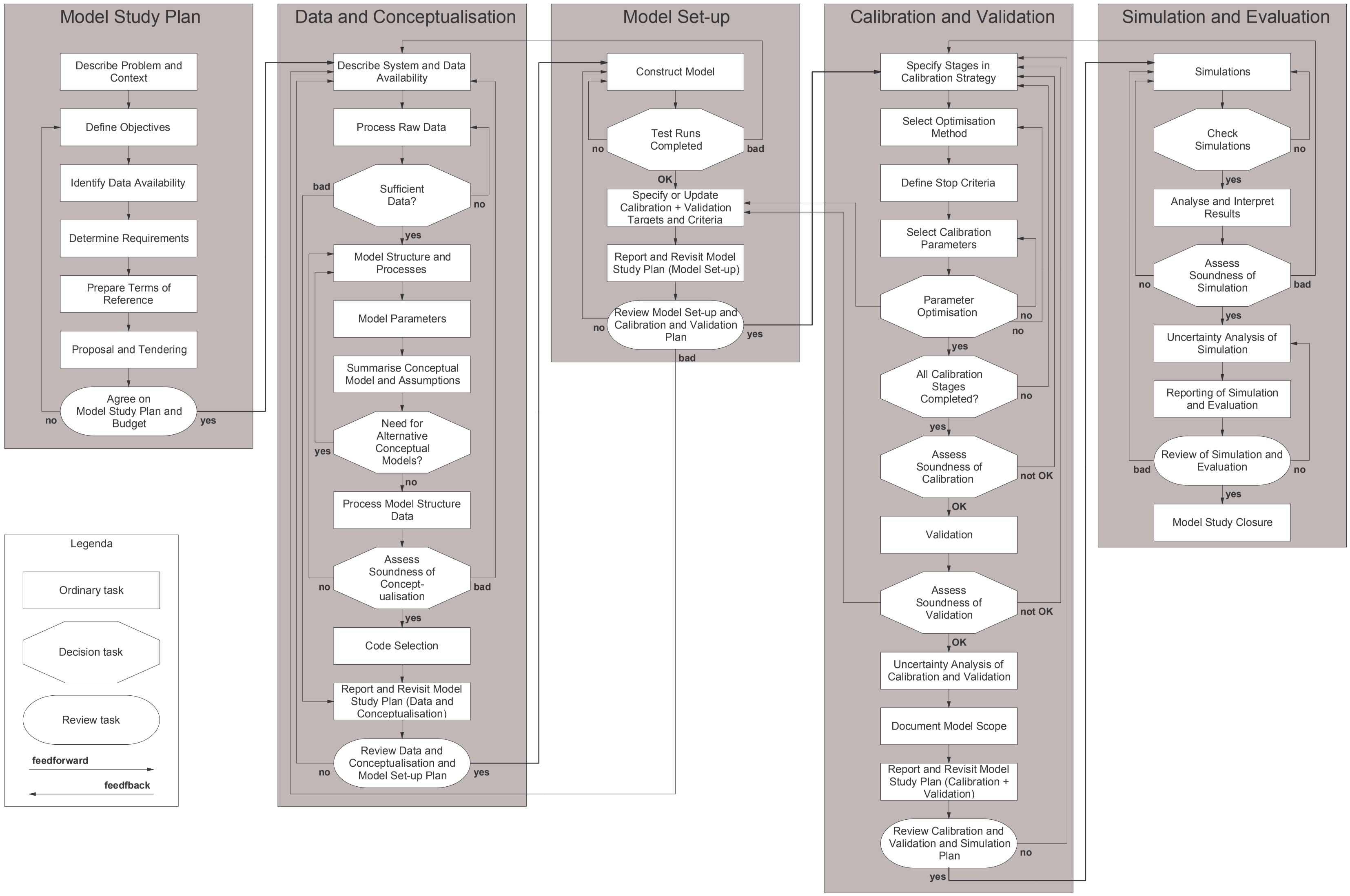

Figure 2. The steps and tasks of the modelling process in MoST's knowledge base (from Refsgaard et al., 2004 with permission).

ELICITATION, DATA UNCERTAINTY and ERROR PROPAGATION EQUATION. In addition to short descriptions of **methods** and their **applicability** the guidelines contain references to where the user can find more thorough descriptions of the **methods** and supporting software tools to use the **methods**.

The exhaustive glossary of relevant terms completes the content of the KB. Glossary entries give definitions with reference to the source of the definition, synonyms and – if required – additional remarks in footnotes. The need for a consistent and explicit terminology has been discussed extensively in Refsgaard and Henriksen (2004) and Refsgaard *et al.* (2005) state that the terminology should be a part of the modelling KB and that it should be presented to guideline users as a glossary.

Support Tool

Design

The support tool MoST (Modelling Support Tool) has been built in a prototyping process, starting with providing just (modelling) guidelines and next adding functionality to monitor and store what team members do in so called (modelling) journals. This version with a limited (still complex) functionality was then tested in 10 test cases of normal commercial model projects. Based on the results of these tests, the functionality of MoST has been extended to assisting multidisciplinary teams co-operating online (internet) in multidomain modelling projects for water management. This has been tested in a second series of test cases and the latter results are used for final improvements.

Functionality

The overall system consists of the KB previously discussed and the support tool, discussed in this section. This system is presented in Figure 3. The support tool consists of four components, together forming the Modelling Support Tool, MoST. These functional components (1) provide *guidance* from the KB to specify what has to be done, (2) *monitor* what the project team members actually do in a modelling project and store this in a model journal, (3) help users in *reporting* what is stored in a model journal and (4) supply *advice* based on model journals of previous projects. The first three functional components have been developed and are integrated in MoST, while the fourth – advice – component is in the design stage of development.

MoST will typically be used to support actual work of multidisciplinary teams in modelling projects. Modelling projects have normally two phases, an initialization phase and a project execution phase. In this respect MoST resembles workflow management tools, which distinguish the same phases in business processes management (Fischer, 2003). MoST corresponds to workflow management software in many aspects, but it differs in other aspects. Opposite to many business processes, consisting of relatively simple tasks, which have to be executed frequently, modelling is a process consisting of many complex tasks, requiring various types of expertise and undergoing improvements based on scientific progress and increased computer power.

In order to facilitate working in groups, the overall software product has been designed in a client-server architecture. To some extent the KB and the tool can be considered as groupware. Modelling teams will often work in a distributed configuration, connected by a LAN or the Internet. A MoST-server contains all shared information (i.e. KB and the work done by a team and stored in the project's model journal). To speed up browsing in the KB, users will work with a local copy, updated when necessary from MoST's central server. The results of a multidisciplinary model-based water management project, i.e. the work actually done, should be safely stored and available for team members that are authorized to use the work of others. Therefore model journals are stored at the server side. MoST-servers can be connected to users by LANs within an organization that want to keep their multidisciplinary model-based problem solving work confidential or connected to users through the Internet for organizations that want to share their work with other distributed persons and organizations.

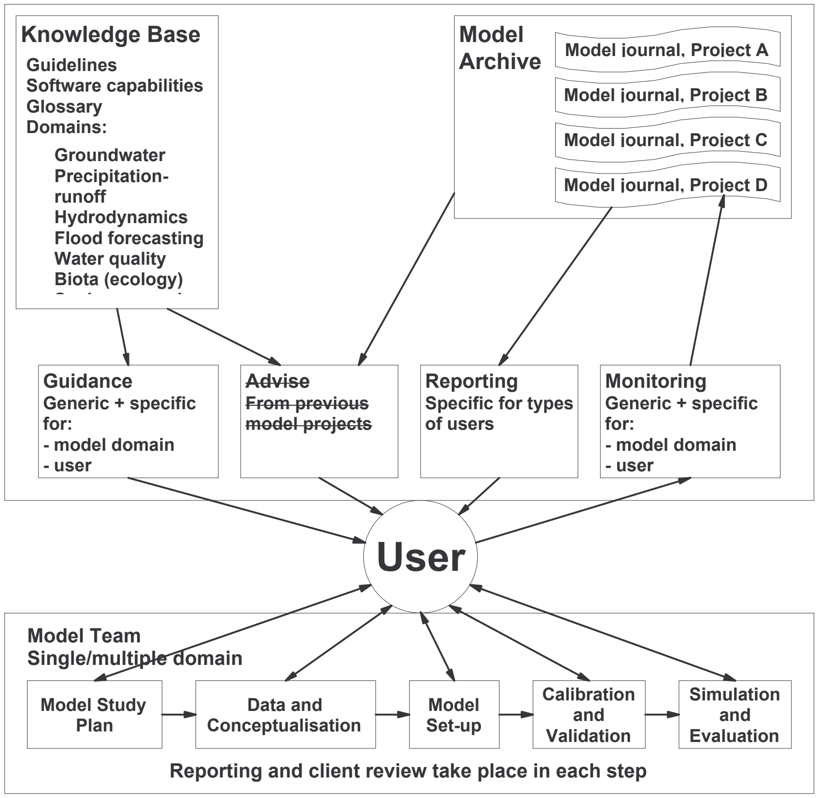

Figure 3. The overall modelling support system consists of KB (upper left corner), MoST (middle part) and model archive (upper right corner). The steps in the work of modelling teams are shown in the lower part. The customization aspect Application Purpose is left out in the guidance and monitoring tool components, as this item is not implemented in MoST.

MoST can also be used as a smart and powerful browser for the KB guidelines. Browsing is supported in three ways. In a linear (textbook) format or according to the flowchart structure of a modelling process represented in the KB or in way most users are familiar with by using a tree structure as is used by most operating systems nowadays. This is realized in the guideline component by providing three panels: a *TREE VIEW* (with an layout similar to MS Windows Explorer) , a *FLOWCHART VIEW* (similar to the structure of Figure 1)and a (textual) *TASK VIEW* (with 'tabs' to facilitate browsing). The guideline component of MoST with these three panels is depicted in Figure 4.

As a modelling project starts, the team member that initiates the project is the initial project administrator. The administrator's first responsibility is to give a name to the project and to specify one or more subprojects, each consisting of one or more domains (not shown). Subsequently the administrator defines which **tasks** have to be done in each of the subprojects, using the *job complexity* templates from the guidelines as starting points (not shown). Next, the project administrator composes the staff of persons to do the project (not shown). Users are added to the team and their roles specified. Then, the administrator will give authorization rights, i.e. reading, writing, decision making, to all persons involved, per subproject and per role and appoint – if functional – extra project administrators (not shown). Finally the administrator can add and edit questions and criteria, to be used by auditors (not shown). A project administrator can change all project settings of an initialization phase during the project.

One or more team members with a role, associated with a specific **task** for that subproject can start a **task** or skip a **task**, preferably with arguments why the **task** is skipped. All team members can see, which **tasks** are completed, skipped, not yet started or in progress.

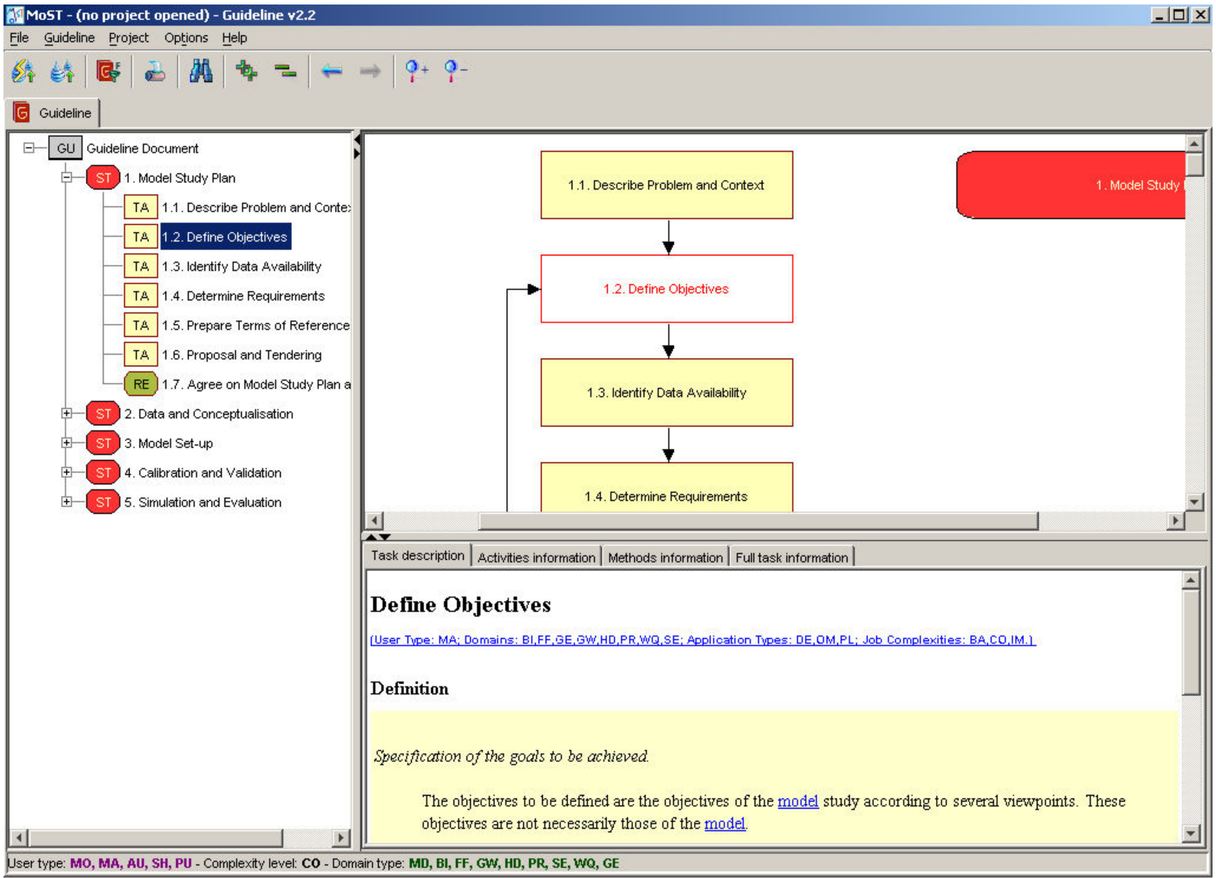

Figure 4. Screenshot of MoST's guidance component with the TREE VIEW in the left, the FLOWCHART VIEW in the upper right and the TASK VIEW in the lower right panel.

In the second phase of a modelling project, team members have to execute the **tasks** according to their role and their authorization. MoST has to collect information about the execution of these **tasks** for monitoring, control and auditing reasons (called keeping a model journal). The main window to perform **tasks** in a modelling project (using the monitor component of MoST) is depicted in Figure 5. In the top-left part of this window, below the main menu, a dropdown menu enables users selecting one of the subprojects to work on. In Figure 5 the *GW study (GW)* subproject has been chosen, dealing with the groundwater modelling issues in this project. In the lower part of the screen the *TREE VIEW* is shown in the left panel. This can be used to browse through the **tasks** to do and also to inspect the status of each **task** in this subproject. Different icons are used to show this status, being a transparent rectangle for **tasks** not yet started, a yellow rectangle for **tasks** started, a green OK sign through the yellow rectangle for **tasks** completed and a red cross through the yellow rectangle for **tasks** skipped. The lower right panel is similar to the *TASK PANEL* in the guiding component of MoST, providing adequate guidance on the **task** selected in the *TREE VIEW* with tabs to select different views on the guidance for that **task**.

The upper right panel is called the *ACTIVITY VIEW* and it is designed to perform the **task** at hand by executing, skipping or completing the **activities** associated with this **task**. This panel is the most complex to handle and it needs therefore more explanation. At the top of this panel MoST keeps track of the start date and time of an **activity**. Below this time stamp box, users can select to start an **activity**, if they are authorized to work on this **task**. The next user, that also wants to work on this **activity**, is allowed to do, but he/she will work in a different copy of the **activity**. The server application of MoST will later merge all work done in a single and consistent model journal of this project. When an **activity** in a **task** has been started, the user will go to the *JOURNAL VIEW*, where the user has to describe in text what he/she did to perform this **activity**, select a **method** to help completing the **activity**, and attach documents in a variety of formats. Such attachments are implemented by providing a hyperlink in the model journal and sending attached documents to the server for later use (reading, editing, printing, etc.). Time stamps of **activities** are also automatically set or updated when an **activity** is later reworked. The list of **activities** at the **task** level uses similar icons to indicate the status of the **activities** as are used for **tasks** in the *TREE VIEW* (the left panel).

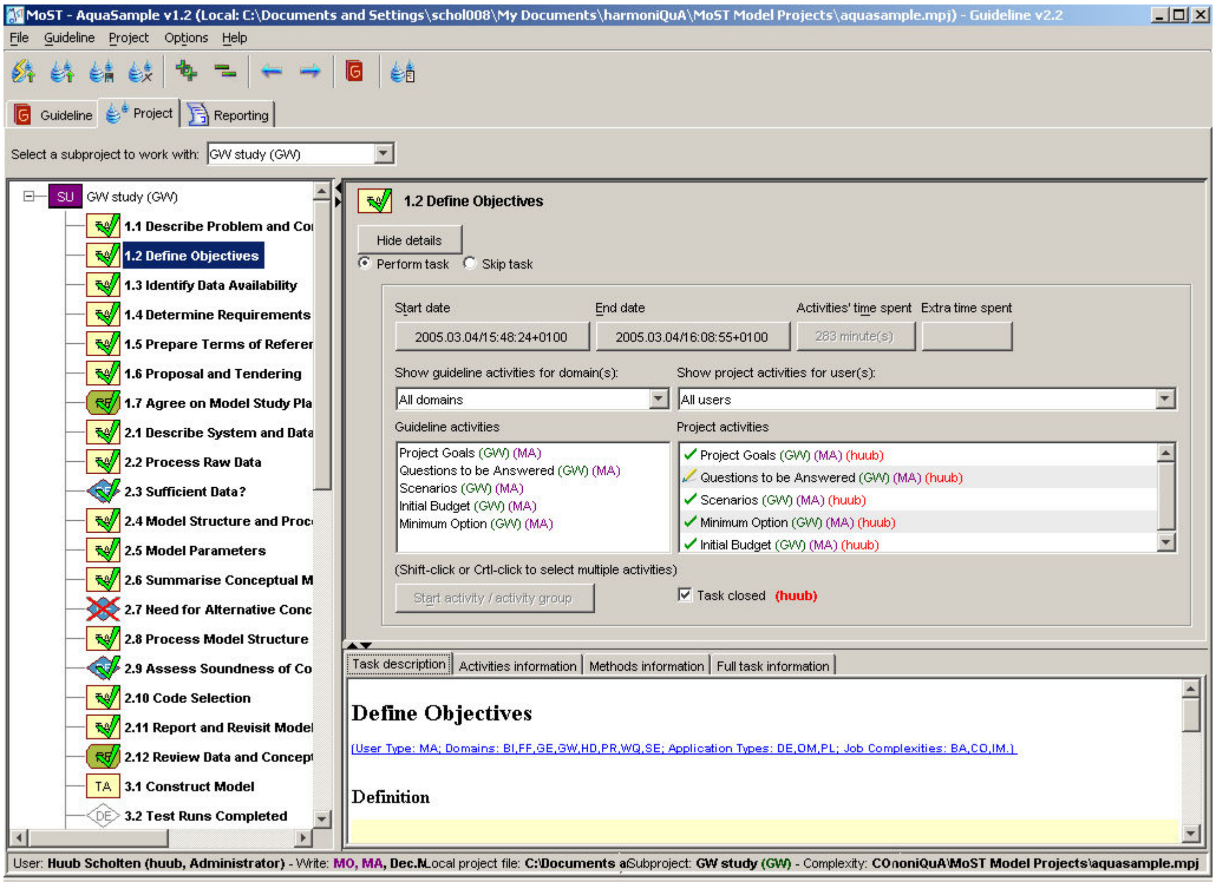

Figure 5. Screenshot of main 'work' window in the project component, where the tasks in a project will be monitored. See text for further explanation.

Decision tasks, presented in the *TREE VIEW* with a diamond shaped icon, require a decision instead of simple completion as in **normal tasks**. Users, authorized to make the decision for a subproject, can choose to continue to the next **task** or to go back to a previous **task** as shown in the *FLOWCHART VIEW* of the guiding component of MoST. **Reviews tasks** are special **decision tasks** and require a decision too, but an essential element of **review tasks** is the discussion between team members with different roles, including water manager, modelers and sometimes others.

Decision and **review tasks** allow users to redo one or more **tasks**. In this way users can redo a model calibration, if they expect to get better results with new settings of the calibration or they can use it for analyzing alternative scenarios with the model at hand or with an alternative model.

Switching to other **tasks**, starting, skipping and completing of **tasks** and **activities**, triggers exchange of information between the client application of MoST and MoST's server application. In that case, the model journal on the MoST-server will be synchronized with the local copy of the model journal that has been changed. At the same time, all other local copies of that model journal will be synchronized with the content of the model journal on the server.

Model journals have an ontological structure, which resembles that of the KB, but with some extra *concepts* and *relations* regarding the time-stamps and the information provided by team members on what they actually have done. This information is stored in instances of the model journal ontology on a MoST-server. The content of a model journal is exchanged between the model journal on the MoST-server and a MoST client (and *vice versa*) as XML-file.

Besides the guidance component and the monitoring functionality in the project component, MoST provides a powerful reporting functionality. This reporting facility filters the myriad of logged information, monitored and stored in a model journal, and transfers it into a readable and compact report according to requirements set by the user. In this way reporting is one of the ways to get an overview of the project progress.

The purpose of the reporting functionality is to provide a report in a form customized for different types of users, i.e. water managers, modelers, auditors, stakeholders and concerned members of the public. The benefit of the audit trail recorded by the monitoring tool will be poor, without a functionality to filter many recorded **decisions** made, **methods** and data used and other information such as time stamps at the **task** level and at the **activity** level. Moreover, some information may be confidential, e.g. some part of the audit trail may be restricted to specific types of users. The reporting component 'understands' the ontological terms from the KB and from model journals, e.g. **step**, **task**, **activity**, **method**, **users** and **user types**, **domains**, **job complexity**, and other **task describing components**. Therefore, the reporting component can handle information requests, which depend on these ontological concepts. These requests are the result of filtering by team members, who select what they want in a report. Subsequently the reporting component collects the requested information from a model journal and enables printing or exporting reports to HTML- or PDF-format. In this way the reporting component facilitates generating audience specific reports.

Training material

MoST is a complex tool and novice users need training before they can benefit from all its features to support modelling teams in their daily routine. Therefore, comprehensive training material has been developed for students and professional modelers in water management. This training material consists of written material, presentations, exercises that encourage using MoST in a test case project and many screen-recording movies on MoST, its knowledge base, a case study and some background information. The movies are the core part of the training material and aim at helping users to work with MoST and act as a sort of animated help facility.

Testing

Scholten and Beulens (2005) have summarized the criteria to test such a KBS, including *verification* (determining that the KBS is built according to its specifications) and *validation* (determining that the KBS actually fulfills the purpose for which it was intended). Many of these criteria are difficult to test, as there are no tools or general applicable methods. Here verification and validation will be combined and referred to as *testing*.

The ontological structure of the KB and the process decomposition are discussed by all partners at project meetings and commented by various (internal) testers and (external) reviewers.

Reading and using the KB were the methods that the testers used to evaluate it. In this way the content of the decomposition elements have been tested according to the following criteria: *correctness* (i.e. capturing intuitions of domain experts?), *completeness* (i.e. no gaps regarding **steps**, **tasks**, **activities**, **methods** and **tools**), *redundancy* (i.e. no unintended synonyms), *consistency* (i.e. different ways of treating the same concept and does the content of the KB include contradictions) and *meaningfulness* (i.e. intended users should be able to understand). These tests were conducted at three levels: (1) internally reviewed by experts (modelers for water management) not involved in developing the KB, (2) used in two series of test cases by professional modellers, where MoST has been used in normal, commercial projects and (3) commented by three external reviewers.

MoST (software) was tested at four levels: (1) by an project partner not involved in the design and implementation of the software on *reliability, correct functioning according to requirements*, (2) in both test series by professional modellers on *adequacy* (i.e. does the support tool adequately support daily practice of professionals), (3) by the external reviewers on *correct functioning*, *reliability* and *adequacy* and (4) by professionals attending workshops on *adequacy* and students attending master degree courses on appropriateness for novel users. Furthermore, all users of the KBS were asked to fill in an online questionnaire. In the workshops and courses the training material has been used, which tests its correctness and usefulness for professionals and students. Testing of training material by using it was further evaluated with the online questionnaires.

A final test is scientific publishing. Many aspects have been published (Refsgaard and Henriksen, 2004, Refsgaard *et al*., 2005, Olsson *et al*., 2004) or are accepted for publication (Scholten *et al*., 2006). Furthermore, the KBS is presented at many conferences and workshops.

Usefulness for other applications

MoST and its KB is designed to support model-based water management, but a claim that it can beneficially support other complex processes too, seems realistic. Unlike workflow management systems, MoST is designed to assist in complex science related processes, which will not be repeated many times. At present this claim is tested within the EC-funded project AquaStress aiming at decision support in a stakeholder participation centered process to mitigate water stress problems (shortage, excess, quality problems, etcetera) throughout Europe. If this is successful, other fields of application will be assessed. Finally, it is considered to extent the functionality in order to support hierarchies of processes too.

Results and Business Impacts

Key Findings

The case study described in this chapter resulted in a knowledge-based system (KBS) that provides guidance and support for multidisciplinary teams working in complex projects, here instantiate for model-based water management. The KBS consists of several components.

The first component is an ontological knowledge base (KB) with levels of increasing specialization, i.e. from rather abstract to describing modelling for water management in all details. The more abstract levels can be re-used for other processes than model-based water management, as is tested at present. This is realized by filling the KB structure (the more abstract levels) with expert knowledge on the new process (dealing with participatory water stress mitigation support), using the second component, i.e. the knowledge base editor. The third component is the support tool, MoST, which has several functions. It presents guidance from the KB to team members, customized for their disciplinary backgrounds and their role in the project at hand. Next it facilitates to keep records on what is actually done by each team member in its monitoring function. Further, it helps generating report, customized for various audiences and purposes. Finally, it aims at deriving advice from previous projects, but this function is not yet implemented. The fourth component of the KBS consists on training material to help novice users to get familiar with MoST and employ it easily in their daily work.

Test results are promising, as they show – next to many bugs and minor shortcomings – that most users (whether professionals or students) like the KBS and perceive it as useful. Nevertheless, the same users expect significant problems with convincing others (i.e. potential users) of its values. The best way to overcome this hurdle is first to persuade managers in their role of clients for projects, for which the KBS is designed. If they are won over, they can enforce its use.

The HarmoniQuA project, in which the KBS has been developed and tested in two series of test cases, partly funded by the European Union, had 12 project partners in 10 countries, each with their own language. One of the major objectives of the KBS is facilitating communication and understanding between members of a multidisciplinary team. The KBS uses English as single language (KB, support tool and training material). In some countries, especially in northwest Europe, the foreign language, English, is hardly seen as hurdle hindering its use by the professional community. In many central and south European countries English will not obstruct researchers to use it, but many consultants that do most of the (routine) modelling work will and cannot use it, unless translated in their language. This is amusing, as the KBS intends to facilitate communication. This language problem may even obstruct the usefulness of the KBS for team members with less professional roles, e.g. stakeholders and concerned members of the public. Translating the KBS will only be partly a solution, as it will introduce a new problem. Maintenance of the KB is now easy, but in the multilingual case, it will be onerous endangering the consistency between the language versions.

The KB structure, implemented in Protégé2000, the KB editor and the support tool MoST represent a promising new technology to support projects dealing with other complex, techno-scientific processes. This is the result of proper design criteria, which ensure a complete split-up of the content of the knowledge base on one hand and the structural aspects of the support tool and the KB on the other hand. In this way, filling of the knowledge base with knowledge related to other processes, results in new systems to run projects by multidisciplinary teams for these other processes. The implementation of the KBS for multidisciplinary model-based water management is a 'proof of principle' of the correctness of the followed approach. The full potential of this technology has still to be proven.

Impacts

The knowledge-based system (KBS) discussed in this chapter has different impacts on various sets of persons involved. *Individual domain experts* (the providers of the knowledge) organized and reviewed their expert knowledge before making it explicit and upload it to the KB. In this way, their daily routine has been improved in the direction of 'best practices'. The same domain experts, but now considered as a *group* discussed this pieces of knowledge, negotiated it to reach agreement on the KB content, which resulted in a further progress towards 'best practices' and consistency in the use of terminology and methodology in the KB. The ontological nature of the KB aims at such consensus and achieving consensus is therefore a major result of this case study.

The *professional community* of modellers for water management (in the Netherlands estimated to be 300-600 persons on a total population of 16 million) appeared to be attracted to the idea of making the knowledge they daily use explicit. Initially they found the support tool cumbersome, but after using it, they perceived it beneficial, as it increases the quality of their work without decreasing their efficiency. Managers in their role as *clients* of modelling projects appeared difficult to interest, but when interested they evaluate the KBS as valuable and often enforce its use.

Undergraduate students found the KBS complex and laborious, but the teachers found that the KBS increased their efficiency and the quality of the students' work. The multimedia training material helped all novice users significantly in familiarizing with the KBS, especially the students. Many professionals expected initially that the KBS is a cumbersome burden, forcing their daily practice in a straitjacket. Training sessions with the multimedia training material helped them to get a more positive view on its usability.

Conclusions

The development of the knowledge based system (KBS) including its ontological knowledge base for multidisciplinary modelling in water management combines knowledge engineering technology with modelling expertise. Modelling team members with different roles and working in different domains of water management get guidance customized for their profile (domain, role, job complexity). This technology seems promising for modelling projects in other application areas than water management and shows potential for supporting other complex, multidisciplinary projects too. This has yet to be proven.

Making modelling knowledge explicit and representing it in an ontology are the major benefits of the KBS discussed in this chapter. The ontological approach makes improving, changing and updating the KB easy. This is an essential prerequisite for ensuring that the KB can become a body of knowledge shared by major parts of the professional modelling community. Its specificity for model-based water management does not hinders extending it to other disciplines or application domains, thanks to the flexibility provided by its ontological set-up. The present state of the KB is a cross section in time of relevant and sufficient modelling knowledge. It is an intermediate product open for improvements and updates, if scientific progress requires.

The ontological approach of MoST's KB passed all stages of an ontological knowledge base development with the design of an ontological structure, the development of a knowledge acquisition tool, the implementation of the KB as instances of the ontological structure and the building of a tool to use the KB for some purpose. This chapter does not focus on knowledge engineering aspects of ontologies and on developing domain factual ontologies, because here the ontological approach was only instrumental.

The development of the KBS and its use in two series of ten test cases seems successful. It solves many of the problems for which it was designed, but several questions are still unanswered. Technically the KB can easily be maintained and updated, but reaching agreement on its content, outside of the shelter provided by an externally financed project as HarmoniQuA, is hard job. Persuading substantial parts of the professional water management community to use the KBS is another hurdle to overcome. Developing this KBS is worthwhile in itself, but it will be worthless if this tool cannot be found in the toolbox of professional modellers for water management.

Practical Tips and Key Lessons:

- Implementation of a complex knowledge-based system (KBS) like MoST and its knowledge base can best be facilitated by convincing clients of multidisciplinary model-based problem solving projects for water management, as they can enforce its use.
- Set-up of an ontological knowledge base requires knowledge engineers that speak the language of the domain experts instead of domain experts that are enforced to do the work of knowledge engineers.
- End-user involvement in the early stages of KBS development helps avoiding crucial design blunders.
- Communicating basic concepts of a KBS with intended users encourages them to use it.
- A Babylonian language problem is an often-neglected issue in knowledge management research.
- The complete KBS (KB, support tool and multimedia training material) can be obtained from www.HarmoniQuA.org/.

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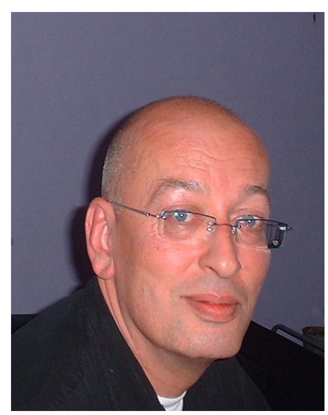

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