Evaluation of CASE Tools with UML Profile Support for Geographical Database Design

Thiago Bicalho Ferreira, Jugurta Lisboa-Filho
Departamento de Informática
Universidade Federal de Viçosa
Viçosa, Minas Gerais, Brazil
e-mail: thiagao.ti@gmail.com, jugura@ufv.br

Sergio Murilo Stempliuc
Faculdade Governador Ozanan Coelho (FAGOC)
Ubá, Minas Gerais, Brazil
e-mail: smstempliuc@gmail.com

***Abstract*— GeoProfile is a Unified Modeling Language (UML) profile developed for the conceptual modeling of geographical databases. It uses the entire UML infrastructure including Computer-Aided Software Engineering (CASE) tools. Additionally, the Model Driven Architecture (MDA) approach along with constraints specified in Object Constraint Language (OCL) can be used in CASE tools to transform models until the generation of Structured Query Language (SQL) source code. This paper describes the evaluation of a set of CASE tools with UML profile support based on specific requirements for the use of the MDA approach, OCL constraints and other elements to aid the conceptual modeling of geographic databases using the UML GeoProfile. Based on the results, geographical databases designers can choose the tool that best suits your project or use the evaluation methodology used here to evaluate other CASE tools.**

Keywords-UML Profile; CASE tools; MDA; OCL; Geographical Database.

I. Introduction

Given the complexity of spatial data, researchers have dedicated themselves for over the last twenty years to adapt original formalisms of the Entity-Relationship (ER) model and the Object-Oriented model aiming to allow the conceptual modeling of geographic databases [1][2].

These researches proposed several conceptual models such as OMT-G [3], MADS [4], GeoOOA [5], UML-GeoFrame [6], Perceptory [1], GEOUML [7], STGL Profile [8], and ChronoGeograph [9]. Moreover, several specific Computer-Aided Software Engineering (CASE) tools have been implemented for these models. The use of several conceptual models and tools then created issues such as the lack of a standard in geographical database (GDB) modeling and the lack of interoperability among the them. In face of such problems, references [10] have proposed a Unified Modeling Language (UML) profile called GeoProfile.

GeoProfile can use all of UML's infrastructure, which includes Object Constraint Language (OCL) to define integrity constraints and Model Driven Architecture (MDA) for the transformation between its different abstraction levels [10][11]. Moreover, one of the advantages of using a UML profile is that it can be used in different CASE tools. However, not all tools offer the same features, which difficult the GDB designer to choose one. Examples of CASE tools with UML support include Enterprise Architect, Papyrus, StarUML, Visual Paradigm, and IBM Rational Software Architect.

In order to compare these tools and in the context of this study, some characteristics or features were prioritized such as the support to the UML Profile definition, validation of OCL constraints, and application of the MDA approach. The key aspect is that the tools need to allow models to be created using UML GeoProfile, the transformation among the different levels established by the MDA architecture, the syntactic e semantic validation of spatial OCL constraints, and that the models should be implemented from scripts generated for a selected database management system.

This paper aims to describe the evaluation of a set of CASE tools considering important requirements from the conceptual project to the implementation of the geographical database.

The remaining of the paper is structured as follows. Section II briefly explains the representation of geographical data, the UML GeoProfile, the MDA approach and the syntax to specify OCL expressions. Section III presents a description of each CASE tool analyzed according to the goal of this study. Section IV shows the requirements, the methodology and the result of the tool evaluations. Section V presents the conclusions and future works.

II. Geographical Database Modeling Concepts

This section presents a literature review identifying the main concepts that contribute to the conceptual GDB modeling.

A. Representing Geographical Information in Computers

The representation of geographical space in computers is a challenge faced by researchers. According to Longley et al. [12], the world is infinitely complex and computing systems are finite, thus, it is up to the designer to limit the amount of details to be captured from the environment mapped. The two main approaches on computing are the continuous (fields) and discrete (objects) representations. Another representation also employed is in the form of networks, which takes into account graph theory.

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Figure 1 shows part of a city with a sports center and represents part of this city focusing on the roads and the stadium. The GDB of Figure 1(b) must be conceptually modeled containing all structures of interest in the system while leaving aside other information such as the type of vegetation, vacant plots, terrain, and other characteristics that may be abstracted from Figure 1(a).

In order to design the conceptual data schema, first the vector structures used to represent the boundaries of each geographic entity must be understood, which is normally specified through basic geometric shapes: point, line and polygon (area) [13]. Figure 1(b) presents the use of these three types of vector structures. For instance, the stadium may be spatially represented as a point or as a polygon (multiple spatial representation); the main east road, as a line; and the sports center, as a polygon.

Additionally, presenting the structures, Figure 1(b) illustrates the relationship among the vector objects, which shows the stadium “is within” the sports center, the sports center “touches” the road to the stadium, the main west road “is near” the sports center, but does not “touch” it.

Such relationships are known as topological relationships and have been discussed by [14] and [15] and used by [16].

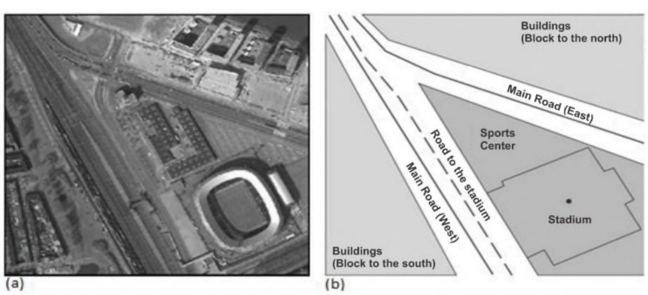


Figure 1. (a) Photograph of part of a city with a sports center between roads. (b) Spatial representation of this area. Source: Adapted from [17].

B. Model-Driven Architecture (MDA)

According to Kleppe et al. [18], MDA is a framework standardized by the [19] for the development of software employing a Model-Driven Development (MDD) view.

The MDA approach consists of three abstraction levels, namely, CIM, PIM and PSM. Computation-Independent Model (CIM) does not show details of the system’s structure, but rather the environment in which the system will operate. Platform-Independent Model (PIM) is an independent model of any implementation technology containing the software requirements. Platform-Specific Model (PSM) specifies details about the platform in which it will be implemented. The artifacts produced by the MDA approach are formal models that can be processed by computers and, after undergoing transformations, will get to a final source-code step (top-down approach) or to high levels of abstraction (bottom-up approach). Figure 2 illustrates the action of transformation tools at MDA levels.

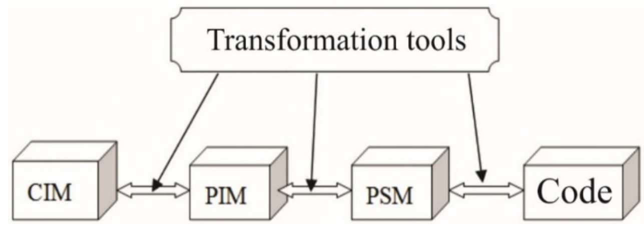


Figure 2. Use of transformation tools in the MDA approach. Source: Adapted from [18].

C. Object Constraint Language (OCL)

Conceptual modeling makes the problem easier to be understood through abstraction, thus enabling risk management and contributing to error correction early in the project, which minimizes the cost of maintenance [20]. However, Warmer and Kleppe [21] state that conceptual models may not be able to represent all requirements, resulting in problems to those who interpret them.

The OCL, adopted by OMG [22] since version 2.0, was defined as a formal language to complement the conceptual modeling using UML. Using OCL ambiguity-free integrity constraints can be created, which makes it possible to specify the data consistency wanted in the system at a high level of abstraction. Since it is a formal language, it can be processed by CASE tools until the source-code generation, which enables more powerful and satisfactory data consistency [21]. OCL is currently at version 2.4 [23].

The OCL expressions represents constraints that are needed in the system and not how they should be implemented. The evaluation of a constraint on the data always yields a Boolean value [21]. The syntax of a typical expression in OCL that represents a condition has the format presented by Code 1.

```
<context>
  inv:<expression>          (1)
```

Code 2 illustrates a hypothetical example of OCL constraint that specifies that a Brazilian municipality must be larger than 3,000 km² (note: The smallest Brazilian municipality, Santa Cruz de Minas, MG, is 3,565 km²). A detailed specification of the OCL can be found in [21] [23].

```
context Municipality
  inv:self.area > 3000      (2)
```

D. UML GeoProfile

In order to provide elements for specific domains without becoming excessively complex, UML has an extension mechanism called Profile. A UML Profile consists of: a metamodel; a set of stereotypes presented through texts in the form of <<text>> or through graphical icons called pictograms; tagged values; and constraints; all grouped in a stereotyped package called <<profile>>, thus formalizing the UML builder extension [24].

GeoProfile is a UML profile proposed for the geographical data modeling comprising the main characteristics of the existing models in the field [25]. GeoProfile is employed at the CIM and PIM levels of the MDA approach, using OCL constraints as a resource to validate the conceptual scheme generated by the designer [26].

The GeoProfile stereotypes are extensions of the Association and Class metaclasses. The stereotypes extended from the Class metaclass allow representing the geographic space in the discrete view (e.g., points, lined and polygons), in the continuous view (e.g., large cells and triangular networks), and through networks (nodes and arcs). The temporal aspects can also be represented with the stereotypes made up of tagged values that store instant and range values. The extended stereotypes of the Association metaclass allow representing topological relationships (e.g., touches and within) among the geographical stereotypes, and the temporal relationship (Temporal) among the temporal objects.

For the extended stereotypes of the Class metaclass, the abstracted stereotypes have been defined: <<Network>>, to group network stereotypes; <<GeoObject>>, to group the discrete view stereotypes; <<GeoField>>, to group the continuous view stereotypes; and <Arc>>, to group the <<UnidirectionalArc>> and <<BidirecionalArc>> stereotypes that represent the possible links between the nodes of a network.

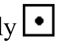
III. CASE Tools Analyzed

The tools analyzed in this study were chosen according to the ease of access to the software and documentation. These tools are open source and commercial with some support to the UML profile and are well known by the software development community. The sub-sections below describe the results of the analysis made on the following CASE tools, exploring the resources they offer compared to the GeoProfile: Enterprise Architect (EA) version 12.0, Papyrus UML2 Modeler (Papyrus) version 1.12.3, StarUML–UML/MDA Plataform (StarUML) version 5.0.2.1570, Visual Paradigm for UML (VP) version 10.2 and IBM Rational Software Architect (RSA) version 9.0.

A. Enterprise Architect (EA)

Enterprise Architect (EA) [27] is a commercial CASE tool licensed by Sparx Systems that allows the visual creation of UML profiles and insertion with syntactic validation of OCL expressions. EA does not offer resources for semantic validation of OCL expressions.

Additionally, being a modeling tool, it acts as an MDA transformation tool, with its own language for transformation between the model levels. This language can be modified so that the users are able to reach the last MDA approach level, the source code [28]. Since the modeling in this paper refers to GDB, the last MDA step is the Data Definition Language (DDL) source code, which EA is able to generate.

The GeoProfile stereotypes in the EA tool can be represented graphically  or textually <<point>>. The tool also offers resources for multiple stereotype representation, e.g., depending on the scale, a city may be modeled as a point or a polygon <<point, polygon>>.

The advantage at using EA is that it does not allow the insertion of extended stereotypes of the Class metaclass in Association elements and vice versa. The problem is that it allows the use of abstract stereotypes in conceptual models, e.g. the abstract GeoProfile stereotypes: <<Arc>>, <<GeoField>>, <<GeoObject>>, <<Network>> and <<NetworkObj>>.

B. Papyrus UML2 Modeler

Papyrus UML2 Modeler [29] is an open-source tool based on the Eclipse environment and licensed by Eclipse (Eclipse Public License). It has a visual environment to insert UML profiles, thus providing support to insertion and syntactic validation of OCL constraints. However, it does not semantically validate these constraints.

Adding graphical icons to the stereotypes is possible. Thus, a class or association can be represented by stereotypes as follows: only text, only graphical icon, or graphical icon and text. The Papyrus tool allows multiple representation to be specified through stereotypes, but, in case the graphical representation is used, only the first stereotype used by the designer is presented.

Additionally, restricting the use of abstract GeoProfile stereotypes in conceptual models, in this CASE tool other GeoProfile stereotypes can only be used with correct UML elements, i.e., an extended stereotype of the Association metaclass cannot be used in a class defined by the Class metaclass.

The Papyrus tool does not support the MDA approach, the transformation language and DDL code generation.

C. StarUML

StarUML [30] is an open-source tool whose profile insertion is done through an Extensible Markup Language (XML) document. This tool does not support OCL and, despite being considered MDA, the features offered are incomplete. What it allows is transforming a model (PIM) into source code without going through the PSM. The source codes can be generated for the languages Java, C++ and C#. StarUML does not have a transformation language and the conceptual models produced from GeoProfile cannot be transformed into DDL source code.

Although multiple stereotype representation is not supported by the tool, the designer can choose between graphical and text representation, but only text is supported in associations. Therefore, the possible class stereotype representations are: textual, graphical, and textual and graphical. The tool can also restrict the use of abstract stereotypes at the same time that the others can be properly used with UML elements.

D. Visual Paradigm for UML (VP)

With an intuitive modeling environment, the commercial tool Visual Paradigm for UML [31] supports the visual creation of UML profiles. The stereotypes can be presented graphically or textually, with support for multiple representation with the graphical ones.

The tool does not allow the use of extended stereotypes of different metaclasses, as described in section A however, it does allow abstract GeoProfile stereotypes to be used during conceptual modeling.

The tool allows incomplete MDA approach, transforming PIM straight into source code. Nevertheless, it does not support DDL code generation from UML class diagrams, just only from those created through the ER model. Thus, the GeoProfile conceptual models cannot be transformed into DDL code.

This tool also does not support the syntactic and semantic validation of OCL constraints on conceptual models created from GeoProfile.

E. *Rational Software Architect (RSA)*

RSA [32] is a commercial CASE tool licensed by IBM that allows the visual creation of UML profiles. This tool supports the use of profiles and is designed to allow syntactic and semantic validation of OCL constraints applied to UML diagrams.

The representations by the stereotypes in an association or class may take place as follows: only textual stereotype, only graphical stereotype, and representation by the textual and graphical stereotypes. However, the multiple representation by the stereotypes can take place in two ways: All stereotypes applied to the class or association must be in textual format or the first stereotype applied takes on the graphical format and the others on textual format.

The tool does not allow inserting extended stereotypes of the Class metaclass in association elements and vice versa, and the stereotypes defined as abstract in GeoProfile cannot be used in the UML elements.

RSA has incomplete support to MDA since it does not natively allow DDL source-code generation. Although there is a transformation mechanism in which the origin, target, and some settings regarding the mapping in the transformation from model into source code can be determined, RSA does not have an MDA transformation language. Therefore, with RSA's native features and mechanisms, these transformations cannot be performed on models created from the GeoProfile.

IV. RESULTS OF THE CASE TOOLS COMPARISON

This section initially presents a set of requirements the CASE tools must meet to support conceptual GDB modeling based on the GeoProfile. Next, it presents the method used in the evaluation, the results and the final classification of the CASE tools analyzed.

This method, originally proposed by Rosario and Santos Neto [33], was used in exploratory research involving software project management tools. This method was also applied by Câmara et al. [34] on comparison of development environments for systems of Volunteered Geographic Information (VGI).

A. *Requirements Survey*

Based on the literature and on the descriptions of each CASE tool, this paper proposes requirements to evaluate which tool has the greatest amount of features to support the GeoProfile use, aiming the transformation of data models at the different MDA levels and to specify integrity constraints at conceptual level using OCL. Table I lists these requirements.

B. *Evaluation Method of CASE Tools*

In the context of this study, the requirements were classified as follows:

- Requirements that are Essentials: Weight 3;
- Requirements that are Important: Weight 2;
- Requirements that are Desirable: Weight 1.

Additionally, to the weight attributed to requirements, a scale must be defined for how well the tools satisfy each one. They may not satisfy (NS), partially satisfy (PS), or satisfy (S) a requirement. Therefore, the following scales can be attributed:

- Does not satisfy the requirement: A scale with value 0 is attributed;
- Partially satisfies the requirement: A scale with value 1 is attributed;
- Satisfies the requirement: A scale with value 2 is attributed.

Based on this evaluation, the classification of each tool was calculated by adding up the products of the importance weight (W) and the satisfaction scale (S) for each requirement (n), represented by Formula (3). References [33] originally proposed this method.

$$X = \sum_{i=1}^{n} S_i . W_i \qquad (3)$$

TABLE I. REQUIREMENTS TO EVALUATE CASE TOOLS

	Requirement description
Rq 01	Correct attribution of GeoProfile stereotypes in the UML elements
Rq 02	Restriction to the use of abstract stereotypes in elements of the model
Rq 03	Support to syntactic validation of OCL constraints
Rq 04	Support to semantic validation of OCL constraints
Rq 05	Support to MDA transformations
Rq 06	Support to transformation language
Rq 07	Support to graphical exhibition of profile stereotypes
Rq 08	Support to multiple representation through stereotypes
Rq09	Support to visual profile creation
Rq 10	Support to DDL code generation
Rq 11	Open-source tool

C. *Evaluation of the CASE Tools*

In order to evaluate each CASE tool and its practical capacity regarding the theoretical functionalities predicted for a UML profile, particularly GeoProfile, the requirements presented in Table I were classified according to the following criteria:

- The requirements considered essential are those that support MDA;

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- Requirements that aid in transformations between MDA models are considered important;
- Requirements that care for quality of the GDB models are considered important;
- Requirements that facilitate understanding and contribute to the adoption of the tool are considered desirable.

Table II presents the classification of the requirements regarding their importance level, which are *Essential*, *Important* or *Desirable*. Table III presents the way each CASE tool satisfies the requirements of Table I. At the end, the summary of the evaluation based on Formula (3) is presented using the data from Tables II and III.

TABLE II. CLASSIFICATION OF THE REQUIREMENTS BASED ON THE IMPORTANCE LEVEL.

Importance	Requirements
Essential	Rq05
Important	Rq 01, Rq 03, Rq 04, Rq 06, Rq 08, Rq 10
Desirable	Rq 02, Rq 07, Rq 09, Rq 11

Table III shows the level of satisfaction for each of the CASE tools analyzed, considering each of the 11 requirements. A CASE tool may or may not support a requirement, or provide partial support. For example, EA offers full support for Rq 01. The assigned scale for this level of satisfaction is 2. Meanwhile, Rq 01 was classified as "important" in Table II, therefore receiving weight 2. So when Formula (3) is applied, the sum of (scale x weight) is calculated for all requirements. Thus, the total sum for EA is 30. The same method was used for all the other tools.

An analysis of Table III shows that the Enterprise Architect tool was the one that best satisfied the requirements for the transformation of conceptual models so that the OCL constraints can be used in the tool. Since it has a customizable transformation language, the OCL constraints can be transformed into integrity constraints along with the SQL code generated in the last MDA level.

Another situation that can be observed in Table III is that the CASE tool RSA provides the best features to use the OCL constraints since it allows for both syntactic and semantic validations.

V. CONCLUSIONS AND FUTURE WORK

With this paper is possible to observe that the tools evaluated do not have features to meet all the theoretical needs of UML, mainly regarding the use of profiles, MDA and OCL. However, they all support conceptual GDB modeling using GeoProfile.

The results of the comparison show that at the time this paper was written the EA could be considered the best CASE tool regarding transformations at the different MDA levels of models created using the GeoProfile. The RSA can be considered the tool that best supports OCL constraints due to its semantic validation, which makes the conceptual models less prone to errors. Among the free-software tools, Papyrus stood out compared to StarUML for supporting the GeoProfile.

Based on the results in this paper, a designer intending to use GeoProfile can know which CASE tool currently best meets the needs of the GDB project. However, it is important to point out that all tools analyzed are being constantly improved, which can change the results of this comparison at any moment.

The method employed, originally proposed by Paranhos and Santos Neto [33], can be used for different comparisons so that designers can establish their own requirements and assign importance weights and satisfaction scales to each one.

As future research, studies are being done aiming to reach interoperability of conceptual geographical data models created from different conceptual metamodels specific for geographical databases, whose transformation base is the GeoProfile metamodel.

TABLE III. CLASSIFICATION OF THE CASE TOOLS

CASE	Enterprise Architect			Rational Software Architect			Visual Paradigm			Papyrus			StarUML		
Requirement	S	PS	NS	S	PS	NS	S	PS	NS	S	PS	NS	S	PS	NS
Rq 01	X			X			X			X			X		
Rq 02			X	X					X	X			X		
Rq 03	X			X					X	X					X
Rq 04			X	X					X			X			X
Rq 05	X				X			X				X		X	
Rq 06	X					X			X			X			X
Rq 07	X			X			X			X			X		
Rq 08	X			X			X			X					X
Rq 09	X			X			X			X					X
Rq 10	X					X	X					X			X
Rq 11			X			X			X	X			X		
Total	30			25			19			20			12		

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