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# A New Methodology to Automate the Transformation of GIS Models in an Iterative Development Process

André Miralles and Thérèse Libourel

**Abstract** In the majority of research today in areas such as evaluation of flood risks, management of organic waste as it applies to plants, and mapping ecological conditions of rivers, scientific advances are often aimed toward the development of new software or the modification of existing software. One of the particulars for software developed for agricultural or environmental fields is that this software manages geographic information. The amount of geographic information has greatly increased over the past 20 years. Geographic Information Systems (GISs) have been designed to store this information and use it to calculate indicators and to create maps to facilitate the presentation and the appropriation of the information. Often, the development of these GISs is a long and very hard process. Since the early 1970s, in order to help project managers, software development processes have been designed and applied. These development processes have also been used for GIS developments. In this chapter, the authors present a new methodology to realize GIS more easily and more interactively. This methodology is based on model transformations, a concept introduced by the Object Management Group (OMG) in its approach called model driven architecture (MDA). When software is developed, models are often used to improve the communication between users, stakeholders, and designers. The changes of a model can be seen as a process where each action (capture of user concepts, modification of concepts, removal of concepts, etc.) transforms the model. In the MDA approach, the OMG recommends automation of these actions using model transformations. The authors have developed a complete set of model transformations that enable one to ensure the evolution of a GIS model from the analysis phase to the implementation phase.

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# 1 Introduction

The development of a software application is becoming increasingly difficult. Since the earliest developments of software, many methodologies have been designed and used to help the project leader in developing software. Over the past 15 years, Ivar Jacobson, Grady Booch, and James Rumbaugh have been major contributors to the improvement of the methodologies used to develop software [12]. They define a **software development process** as *the set of activities needed to transform a user's requirements into a software system* (Fig. 1).

These authors have also formalized the various “ingredients” taking part in the process of developing a computer application. This model is called the 4Ps model (Fig. 2).

This model dictates that the **Result** of a **Project** is a **Product** that requires **People** in order to describe the studied domain (actors) and to manage it (analysts, designers, programmers, etc.). The realization of the **Project** is conducted in accordance with **Templates** defining, organizing, and explaining the successive steps of the development **Process**. In order to manage the development **Process**, **Tools** facilitating the expression of the needs, the modeling, the project planning, and so forth, are needed.

This description of the development process paints a set of variety of topics and issues that a project manager in charge of application development should address. To illustrate the intrinsic complexity of a development, Muller and Gaertner [21] use two metaphors reported here *in extenso*:

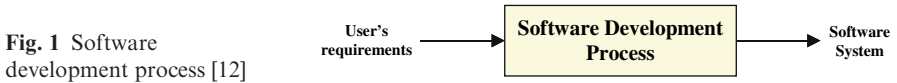


Fig. 1 Software development process [12]

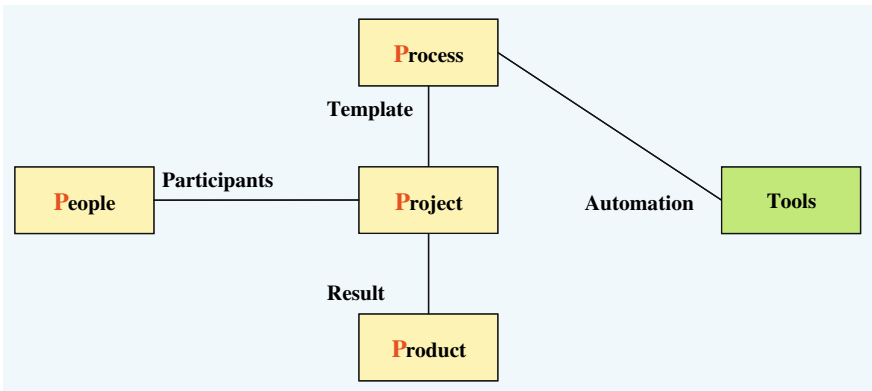


Fig. 2 The 4 Ps software development process [12]

- 91 • The first one is related to the management of the project: the development of  
92 software can be seen as the crossing of an ocean in a boat. The departure day  
93 is known; the arrival is not so well-known. In the course of the trip, it will be  
94 necessary to brave storms and to repair damage.
- 95 • The second one concerns the multidisciplinary character of necessary com-  
96 petencies to make a development. They write: if the computer programmer  
97 had produced furniture, he would begin by planting acorns, would cut up  
98 trees into planks, would dig the soil in search of iron ore, would manufacture  
99 ironworks to make his nails, and would finish by assembling everything to  
100 obtain a piece of furniture. . . . A mode of development which rests on the  
101 shoulders of some heroic programmers, gurus, and other magicians of soft-  
102 ware does not constitute a perennial and reproducible industrial practice.

103 These two metaphors perfectly illustrate the challenge with which the project  
104 leader and the programmers are confronted when they take on the realization of a  
105 data-processing application. This challenge is not entirely imaginary. The statistics  
106 of Ref. 30 give an idea of the difficulty. **According to these statistics, the failure risk  
107 of the development of an application is 23%, the risk of drift is 49%, and only 28%  
108 of the developments have to finish in delay and in the projected budget.** These  
109 figures are from an investigation carried out on more than 150,000 developments  
110 achieved in the United States in 2000. It is noteworthy that in this investigation, the  
111 developments aimed at creating a new application are grouped with those aimed at  
112 the evolution of an existing application. Thus, it is quite likely that the figure of  
113 28% is overestimated, as the failure risk linked to achieving a new application is  
114 much larger than the risk linked to the evolution of an application.

## 117 2 The Software Development Process

119 The creators of the Unified Modeling Language (UML) have deliberately failed  
120 to define a methodology to successfully carry out a project of development [8]  
121 in order to let each designer freely choose the most suitable method adapted to his  
122 professional environment. Generally, the designer uses methods of project lead-  
123 ing with the aim of *increasing the satisfaction level of the customers or of the  
124 stakeholders while making the development work easier* [3] and more rationally

125 There are a wide variety of software development processes that can be  
126 classified into two large families:

- 128 • The so-called traditional methods (waterfall life-cycle, V life-cycle, spiral life-  
129 cycle, unified process, rapid application development, etc.) are derived most  
130 often from the methods used in industrial engineering or in civil engineering  
131 (i.e., building and public works sector) [17].
- 132 • The *agile* methods, of which the most important are extreme programming,  
133 dynamic software development method, adaptive software development,  
134 **SCRUM** [3, 17], and so forth. Their major characteristics are their potential  
135 for adaptation and *common sense in action* [3].

AQ1

AQ2

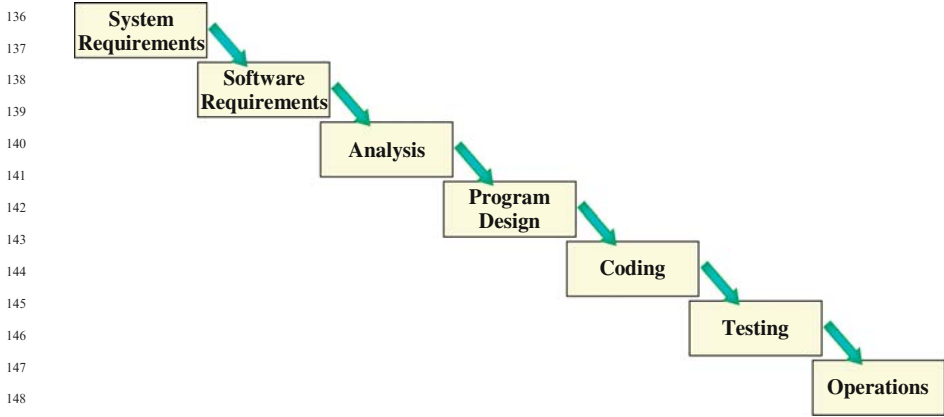


Fig. 3 The 4 Ps software development process [26]

The software development processes that were used in the 1970s were essentially of the linear type (Fig. 3); that is to say that the analysis was conducted at the start of the project. Then, the development of the application was conducted, step after step, without any intermediate validation from users, stakeholders, or sponsors. At the end of the process, the application was presented to the stakeholders. It was not rare that the application did not correspond with the needs of the users, the stakeholders, or the sponsors. In this case, the project manager was professionally in a difficult position, especially if the duration of the development was long (several months and even 1 or 2 years).

This situation is hardly surprising because it is difficult, and even impossible, for the users or the stakeholders, *to conceive the solution in its whole* [5]. This report is all the more true when the scale of the project is substantial.

To avoid facing this type of situation, the project managers have appealed more and more to the users and the stakeholders during the development process to validate the application progress.

The experience cumulated during this type of development processes enables better formalization of the participation of the stakeholders in the development of computer applications and allows for the proposal of new methods to conduct the project. The unified process method and extreme programming method are two key methods coming from this line of thinking.

The unified process method, relying on the modeling language UML, is the synthesis of the best practices of software development over three decades in various fields<sup>1</sup> [12]. It assumes the adoption of the following four principles: the development process should be *use-case driven*, but it should also be *iterative and incremental*, *architecture-centric*, and *risk-centric* [16, 21, 25].

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<sup>1</sup> Telecommunication, aeronautic, defense, transport, and so forth.

181 The *use-case driven* development principle has been introduced by Ivar  
182 Jacobson [11] in order to pilot application development according to the  
183 requirements of the users or the stakeholders. A use-case is *a sequence of actions,*  
184 *including variants, that a system (or other entity) can perform, interacting with*  
185 *actors of the system* [23]. This concept enables one to describe what the system  
186 should do. Once implemented, a use-case compulsorily resolves a requirement.  
187 If this is not the case, it is because the need was not properly described. Thus, it  
188 is important to describe the use-cases at the beginning of the project. In this  
189 vision, the use-cases can be used as a planning tool during the development.

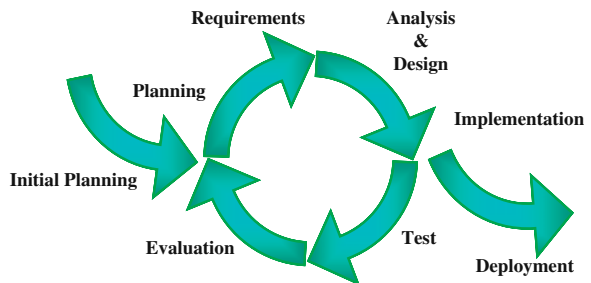
190 The *iterative* development process (Fig. 4) has been designed to prevent the  
191 drawbacks caused by linear development. In order to do this, the system is  
192 structured into subsystems, and for each iteration, a subsystem is analyzed and  
193 implemented. Therefore, the model evolves following an *incremental* process.  
194 For Ivar Jacobson, *an increment is the result of an iteration* [12] that lasts  
195 between 2 and 4 weeks.

196 The principle of a development process that would be *architecture-centric*  
197 assumes that the structuring in subsystems must not be a simple description of  
198 the system under a graphic or a textual form, but that it should be materialized  
199 by a model in a *case-tool* [25].

200 The aim of a *risk-centric* development is to put as a priority the achievement  
201 of the systems or subsystems for which the designers have the least experience:  
202 implementation of new technologies, for instance. This principle of develop-  
203 ment enables one to take issues into account very early and to process them by  
204 anticipation.

205 Extreme programming [1, 4] is a method called *agile*, which recommends  
206 reducing activities that are not closely related to the production of a code,  
207 including documentation. The code is the main part of the production of the  
208 team. This method is hence often qualified as code-centric development. It is  
209 representative of the agile methods that rely on four values:

- 211 • **Communication** between the users, the stakeholders, and the designer to  
212 prevent situations described in the waterfall method.
- 213 • **Simplicity** of the code so that it is easily understandable and it is possible to  
214 integrate changes.



224 **Fig. 4** Typical iteration flow  
225 in unified process [15]

- 226 • **Feedback**, which should be quick from the stakeholders and from the other  
227 members of the development team, enables the developer to have informa-  
228 tion on the quality of his development.
- 229 • **Courage** to tell things as they are and to make difficult decisions like chang-  
230 ing a code structure or throwing it away [6].

231 The fulfillment of these four values is ensured by 12 practices with the aim of  
232 encouraging *quick feedback*, favoring the *incremental evolution* of the code,  
233 seeking *simplicity* in the produced code, and targeting the *code quality*.

234 Among these practices, that of *customer on-site*<sup>2</sup> is probably the most impor-  
235 tant. The aim of this practice is to fluidize the communication between the  
236 customer and the programmers by hosting the customer or his representative  
237 within the team. This practice ensures a strong reactivity and a high feedback.  
238 The main aim of this practice is to make up for the lack of detailed specifications.

239 The main task of the customer is the writing of the *user stories*, which will  
240 allow one to code the functionalities of the application. A second task that is  
241 just as important as the first one is the determination of the tests that the tester  
242 should implement to validate functionalities. The customer acts by fixing the  
243 priorities among the functionalities, by stating the specifications that have not  
244 been previously defined or that have remained fuzzy during the previous  
245 discussions, and so forth.

246 The presence of the customer in the team enables him to see the immediate result  
247 of his work of specification and to evaluate the progression of the application. This  
248 closeness also enables him to quickly assess the relevance of his specifications. If the  
249 project drifts or progress is slow, he will immediately realize it.

250 Actually, the practice of *customer on-site* gives a high level of interactivity to  
251 the development process, which associated with practice of the test-driven  
252 development reduces the number of bugs by a factor of 5 in some cases.  
253

### 254 3 The Model Driven Architecture<sup>3</sup>

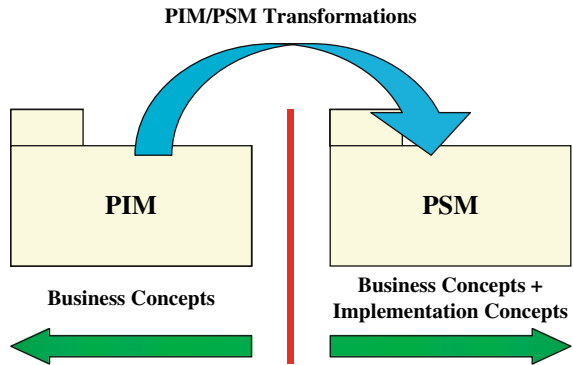
255  
256 Model driven architecture (MDA) is a software design approach proposed by  
257 the Object Management Group (OMG) with the objective of improving applica-  
258 tion developments. It was conceived and formalized in 2001 to improve produc-  
259 tivity but also to resolve problems of software portability, software integration,  
260 and software interoperability encountered during developments [14].  
261

262 To achieve this objective, the MDA approach recommends that designers  
263 separate the specification of system functionality from the specification of the  
264 implementation of that functionality on a specific technology platform [18]. For  
265 that, the authors of this approach suggest use of two types of models: the  
266 platform independent model (PIM) and the platform specific model (PSM).  
267

268 <sup>2</sup> Part played by customer or his representative or failing by a member of the team.

269 <sup>3</sup> See Chapter 1, “The Model Driven Architecture Approach: A Framework for Developing  
270 Complex Agricultural Systems.”

271 **Fig. 5** Illustration of the  
 272 separation of concepts and  
 273 of the transformation notion



284 PIMs are models providing a description of the structure and functions of the  
 285 system independently of platform specifications. PSMs are models defining  
 286 how structure and functions of a system are implemented on a specific platform.

287 In fact, the MDA approach introduces a separation between concepts and  
 288 specifications needed to develop software. PIMs only contain business con-  
 289 cepts, whereas PSMs contain implementation concepts. Because all the PIM  
 290 business concepts are included in PSMs, a PIM can be seen as a modified subset  
 291 of a PSM [7]. Therefore, a PSM always derives from a model PIM through one  
 292 or more transformations [18, 19].

293 Figure 5 illustrates this separation and transformation. If different platforms  
 294 are used for the implementations (e.g., same standardized model implemented  
 295 into different organizations), then more than one PSM may be derived from the  
 296 same PIM.

297 The previous transformations, called PIM/PSM transformations, are not the  
 298 only ones. In fact, the authors of MDA mention on the one hand the existence  
 299 of PSM/PIM transformations converting a PSM into a PIM and, on the other  
 300 hand, transformations whose model sources and targets are of the same stand-  
 301 ard (PIM/PIM transformations or PSM/PSM transformations).

302 In the process of development, PSM is not the last step as it is then necessary  
 303 to project this model into a programming language. This projection is often  
 304 considered as a transformation.

## 306 4 The New Interactive Development Method

### 308 4.1 *The Principle of the Continuous Integration Unified* 309 *Process Method*

310  
 311  
 312 For about 40 years, the major aim of research bearing on the methods of  
 313 development of computer applications has been to reduce the gap between the  
 314 needs of the actors (users, clients, stakeholders, etc.) and the end product. To  
 315 achieve this, the authors of the methods of development seek to associate and to



316 involve more and more the actors, who are the only ones that have a good  
317 knowledge of the studied system.

318 In the waterfall life-cycle, the actors act in the analysis phase at the start of the  
319 project, before the development team carries out the application, theoretically  
320 without any other participation of the actors. Practically, the actors mostly act  
321 when the project is of a significant size, but their interventions are not formalized.

322 In the unified process method, the iterative cycle requires organization of  
323 periodic meetings among the actors of the domain occurring at the beginning of  
324 each iteration, in the analysis phase, and at the end of the iteration to validate  
325 the iteration product.

326 The practice of customer on-site of the extreme programming method leads  
327 to the hosting of a representative of the actor within the development team.  
328 Within this framework, the actor is at the center of the development.

329 Actually, the increased participation of the actors enables, on the one hand,  
330 improvement in the capture of knowledge and the expression of the actors'  
331 needs and, on the other hand, to have, at a more or less continuous frequency,  
332 the validation of the evolution of the application. With this type of process, the  
333 semantic side of the application is of a higher quality. The direct consequence is  
334 that the increment developed during the iteration is more stable.

335 Building on that report, the authors have designed a new method called the  
336 *continuous integration unified process*, which allows an increase in the interac-  
337 tivity between the actors and the designer.

338 This new method is an extension of the unified process method incorporating  
339 some practices of the extreme programming method. It is based on the follow-  
340 ing report: in the analysis phase, the actors are in a situation similar to that of  
341 the customer on-site in the extreme programming method (see Section 2) – they  
342 are at the heart of the analysis. As communication is the key value of the  
343 extreme programming method, any technique or method increasing it will result  
344 in improvement of the quality of the end application. Dialogue around a  
345 prototype is one of these techniques or methods.

346 It is not rare that during the development of an application, one or several  
347 prototypes are produced so that the actors have a better understanding of what  
348 the end application will be. Then, the actors implicitly validate the concepts of  
349 the field and, if it is a “dynamic prototype” [24], they validate the assumed  
350 functionalities corresponding with their requirements. A prototype is a device  
351 that fluidizes the exchanges between the actors and the designer, but it also  
352 increases the area of shared knowledge [10] called *commonness* [27]. Moreover,  
353 the implementation of the prototype accelerates learning by the actors of the  
354 modeling language used by the designers [10].

355 The qualities of the prototype have led the authors to formalize its use in the  
356 analysis phase, a key phase for the capture of the knowledge and the actors'  
357 requirements.

358 To generate a prototype requires similar development to that of the final  
359 application. In this background, the development process includes simplified  
360 analysis, design, and implementation. If all the activities to develop the

prototype are done manually, the analysis will be interrupted by nonproductive slack periods that will prove to be expensive.

This exercise of analysis will quickly become tedious for the actors, and they will become demobilized and lose interest in the exercise. The result is that the analysis could be less relevant and the quality of the application could deteriorate. On the other hand, if the same activities are automated, then the slack periods do not exist, and the response of the actors to the prototype will be better than in front of a model for which all the finer points of the modeling language are not known. Then, the development process of the prototype is made according to a cycle with a very short duration, which is qualified as *rapid prototyping*.

Building on these thoughts, the definition of the new method is the following: the continuous integration unified process method superimposes, on the main cycle of the unified process method, a cycle of rapid prototyping (Fig. 6), which is provided with a process automating the evolution of the models from the analysis to the implementation.

The idea of automatic evolution of the models from the analysis up to the implementation can also be found in the concerns of the MDA community. It is obvious, from reading the fundamental texts of this approach [18, 19], that this was one of the objectives that were sought. Some authors [13, 28] describe as full MDA the complete automation of the evolution of the models. The *common warehouse metamodel* (CWM) standard [22] has been created to cover the complete cycle of design, completion, and management of the data warehouses [18].

Naturally, the challenge remains to design and implement a complete set of model transformations assuming a full MDA process. The authors reach such a

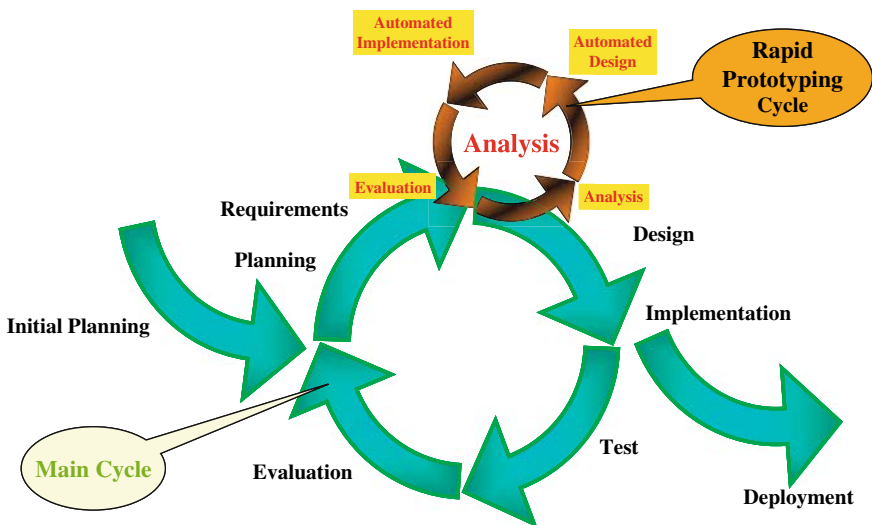


Fig. 6 Continuous integration unified process

406 challenge in generating automatically the structure of the database of a Geo-  
407 graphic Information System (GIS).

408 Given such a set, the duration of the phases of design and implementation of  
409 the cycle of rapid prototyping is reduced to the unique time of completion of these  
410 transformations, time linked to the volume of concepts contained in the models.

#### 411 412 413 ***4.2 The Software Development Process Approach: 414 A Generalization of the MDA Approach*** 415

416 When an application is developed, one of the main preoccupations for a project  
417 manager and for the company in charge of the software development is the  
418 capitalization of knowledge and the re-use of the knowledge accumulated  
419 during development.

420 The capitalization of knowledge is not just the problem of separating the  
421 business concepts and implementation concepts according to the MDA vision  
422 presented in Section 3, as at each phase of the development, the type of mobilized  
423 knowledge is different. Thus, another approach involves capitalizing on the  
424 knowledge at each phase of the application development process. The *software*  
425 *development process approach* proposed by the authors is founded on this report  
426 [20]. Thus, in this new approach, a model is associated at each one of the phases.

427 In fact, this approach generalizes the MDA approach by refining the PIMs  
428 into three types of models: the analysis model, the preliminary design model,  
429 and the advanced design model. The first one is used to analyze the system with  
430 the actors, the second one is dedicated to the concepts coming from a domain in  
431 relation to the studied domain (point, line, or polygon from geomatic domain,  
432 for example), and the third is specialized for the description of the computer  
433 concepts or models independent of the programming language (ASCII files,  
434 host, for example). Although the refinement of PSMs is theoretically possible,  
435 we have not worked on this subject for the moment.

#### 436 437 438 ***4.3 The Software Development Process Model: A Modeling 439 Artifact for Knowledge Capitalization*** 440

441  
442 To apply the software development process approach, archiving models after  
443 each phase is a solution that is often used, even if it is not formalized. Often,  
444 these archives are also physically independent, so any change, including, for  
445 example, changing the name of a concept, quickly becomes attempting the  
446 impossible, as it is difficult and expensive to pass along the change to all the  
447 archived models. Quickly, the models diverge and their coherence deteriorates.

448 *Software development process model* (SPDM) is an artifact that enables one  
449 to keep the models associated with the phases of development coherent. It has  
450 been conceived and implemented by Miralles [20] into case-tools. This modeling

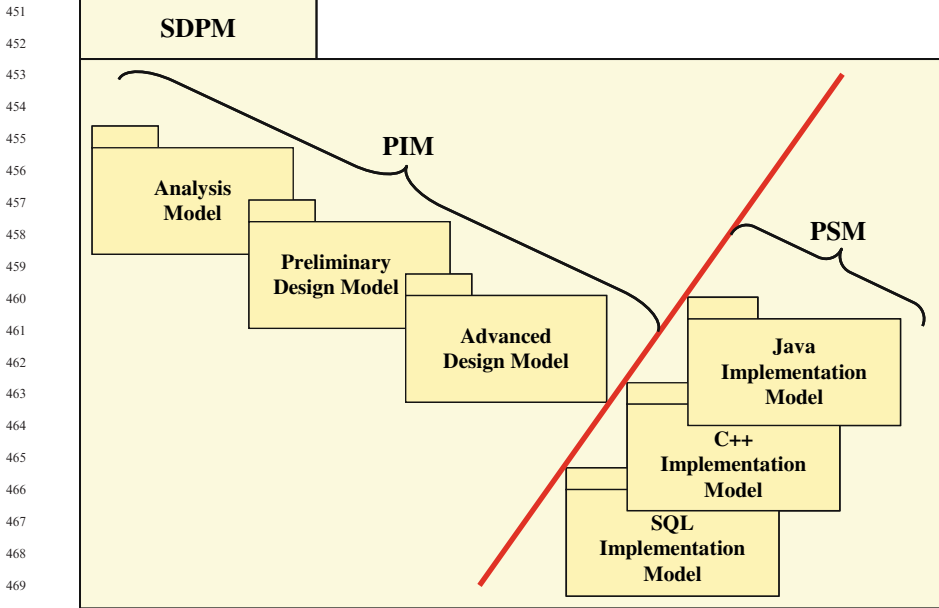


Fig. 7 The software development process model

artifact contains the different models associated with the phases of the software development process. In the vision of the authors, the software development process model is the MODEL of the application under development.

Figure 7 shows the software development process model for the development of software following the *two-track unified process* method [25], a method derived from the unified process method. This figure also shows that the PIM/PSM separation introduced by the MDA approach occurs when the project moves from the advanced design phase to the implementation phase.

#### 4.4 The Complete Set of Transformations Enabling a Full MDA Process for Databases

To realize a full MDA<sup>4</sup> process for GIS, the first set of transformations implemented into the case-tool is in charge of diffusing the captured business concepts from the analysis model to the implementation models (see Section 4.4.1).

<sup>4</sup> Normally, a full MDA process must include the model verification and the model compilation. Currently, the model verification is not made but it is one of the future subjects of research. The model compilation is held by code generators (C++ and C#, Java, Corba, and SQL) proposed by case-tool.

496 To describe the spatial properties (point, line, and polygon) and temporal  
 497 properties (instant and period) in the analysis model, the authors adopted the  
 498 pictogrammic language of Perceptory [2]. These pictograms are introduced into  
 499 the business concept via stereotypes (UML concepts with which it is possible to  
 500 associate a pictogram). In the analysis model, the stereotype/pictogram couple  
 501 only has an informative value. The second type of transformation developed  
 502 reifies the stereotype/pictogram couple into UML modeling elements (see  
 503 Section 4.4.2).

504 Finally, the last type of transformation developed is in charge of adapting the  
 505 SQL implementation model after cloning the SQL code generator of the case-  
 506 tool (see Section 4.4.3).

#### 509 4.4.1 Diffusion Transformation and Management of the Software 510 Development Process Model

511 This transformation clones a concept from a source model into the next model.  
 512 Step by step, the concepts captured in the analysis phase and added into the  
 513 analysis model are transferred to the implementation models.

514 To guarantee the consistency of the software development process model, a  
 515 *cloning traceability architecture* is automatically built by the *diffusion transfor-*  
 516 *mation*. After cloning, this transformation establishes an individual cloning  
 517 traceability link between each one of the source concepts and the cloned con-  
 518 cepts. Figure 8 illustrates the cloning traceability architecture.

519 In an iterative development process, the *diffusion transformation* adds, with  
 520 every iteration, a new clone of the same source into the following model. To  
 521 avoid this problem, when an individual cloning traceability link exists, the  
 522 *diffusion transformation* does not clone the concepts but only carries out one  
 523 update of the clone.  
 524  
 525  
 526

#### 527 4.4.2 The GIS Transformations

##### 529 The GIS Design Pattern Generation Transformation

530 The spatial and temporal concepts have stable relationships that are completely  
 531 known. They constitute recurrent minimodels having the main property of  
 532 design patterns<sup>5</sup>: recurrence [9]. It is this property that led authors to call  
 533 these minimodels *design patterns*. These GIS design patterns do not have the  
 534

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535  
 536 <sup>5</sup> A design pattern systematically names, motivates, and explains a general design that  
 537 addresses a recurring design problem in object-oriented systems. It describes the problem,  
 538 the solution, when to apply the solution, and its consequences. It also gives implementation  
 539 hints and examples. The solution is a general arrangement of objects and classes that solve the  
 540 problem. The solution is customized and implemented to solve the problem in a particular  
 context [9].

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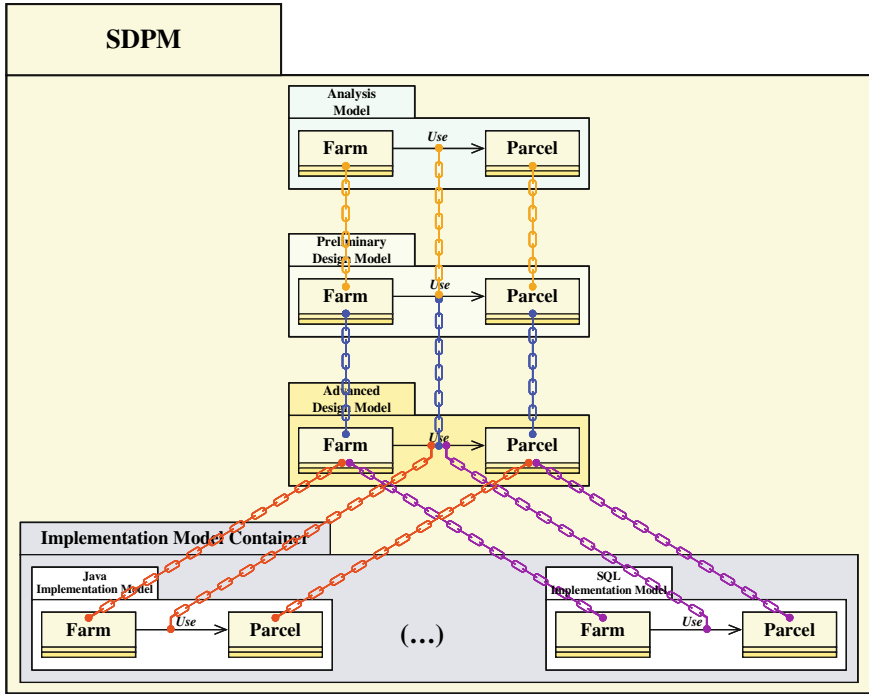


Fig. 8 Example of the cloning traceability architecture

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same statutes as the design patterns described in Ref. 9, but they are fundamental design patterns in the geomatic domain. Figure 9 shows an example of design pattern of the GIS domain. The set of these patterns is called the *GIS design pattern*.

570  
571  
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573

Given that the design patterns are always identical, they can be automatically generated with a case-tool without any difficulty. The *GIS design pattern generation transformation* is the transformation in charge of generating the set of GIS design patterns.

574  
575

The Pictogram Translation Transformation

576  
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579

Once the GIS design patterns have been created, the business and the spatial or temporal concepts represented by the pictogram are totally disassociated (Fig. 10, "Before"). The goal of the *pictogram translation transformation*  $T_p$

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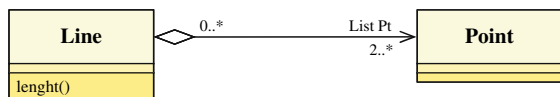


Fig. 9 Example of a GIS design pattern

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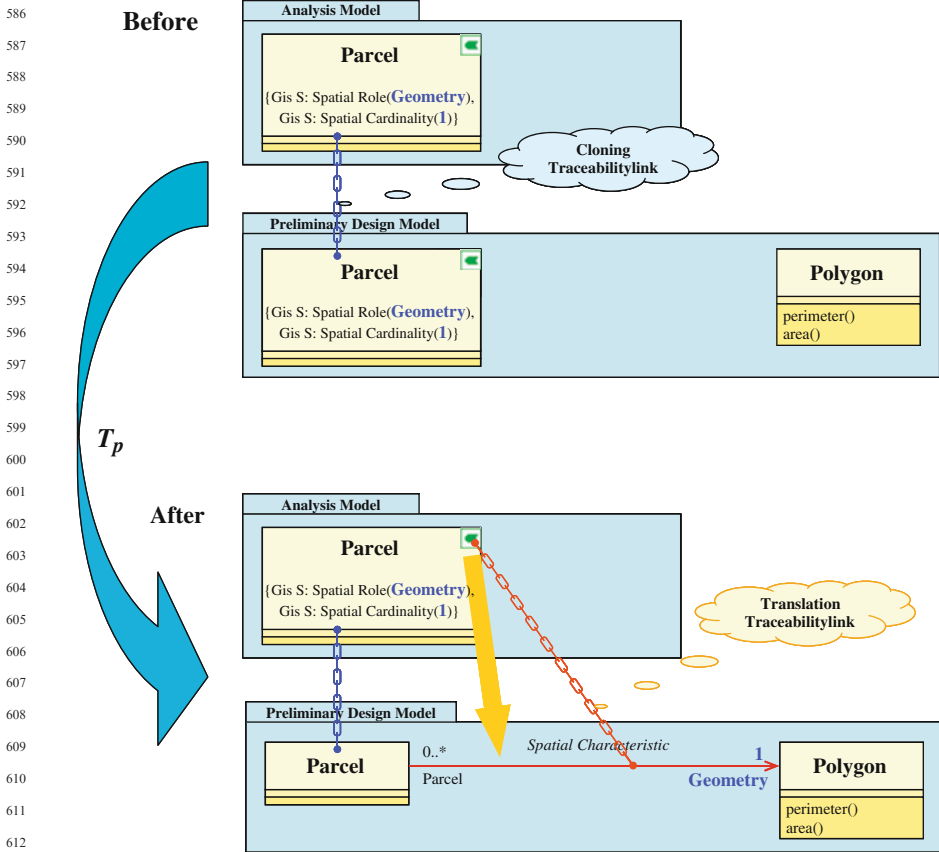


Fig. 10 The pictogram translation transformation  $T_p$

(Fig. 10) is to automatically establish a relationship between the *Parcel* and *Polygon* concepts. This transformation creates an association, called *spatial characteristic*.

During the capture of the pictogram, two tagged values are added to the business concept to specify the role of the spatial concept ( $\{Gis S: Spatial Role(Geometry)\}$ ) and its cardinality ( $\{Gis S: Spatial Cardinality(1)\}$ ). By default, this role and this cardinality have the values *Geometry* and *1*, respectively, but the designer can subsequently modify them. In this association, the entity name has been allocated to its role, *Parcel* in this example, and its cardinality value is 0.1. Once the association has been created, the stereotype/pictogram and the two tagged values are deleted because this information becomes redundant with the association.

To ensure traceability, the transformation  $T_p$  creates a traceability link, called *translation traceability link*, between the pictogram of the business entity of the analysis model and the *spatial characteristic* association.

### 4.4.3 The SQL Transformation

To achieve a full MDA process, the SQL transformation  $T_{SQL}$  has been conceived and implemented. It is applied on the SQL implementation model. The objective of this transformation is to adapt the SQL implementation model after cloning (Fig. 11, “Before”) to the SQL code generator of the case-tool. To do this, it adds SQL concepts, such as persistence and key primary (Fig. 11, “After”), to the business concepts. These SQL concepts are not systematically added to all the business concepts but only to a certain number of them.

Persistence is an “SQL” property that should be added to all concepts that should be converted into tables (Fig. 11, “After”). Considering that the “son” concepts involved in a hierarchy of business concepts inherit properties of “father” concepts, the persistence property should be put in the “root” concept of the hierarchy.

Although the primary key properties are as essential as the concepts involved in a relationship of association, of aggregation, or of composition, the transformation  $T_{SQL}$  systematically adds the primary key property on all the persistent classes (Fig. 11, “After”). Just like for persistence, the “son” concepts of a hierarchy of concepts inherit the primary key of the “root” concept.

Annotated with SQL concepts, the SQL code generator can be applied on the SQL implementation model to produce the SQL code for creating the database.

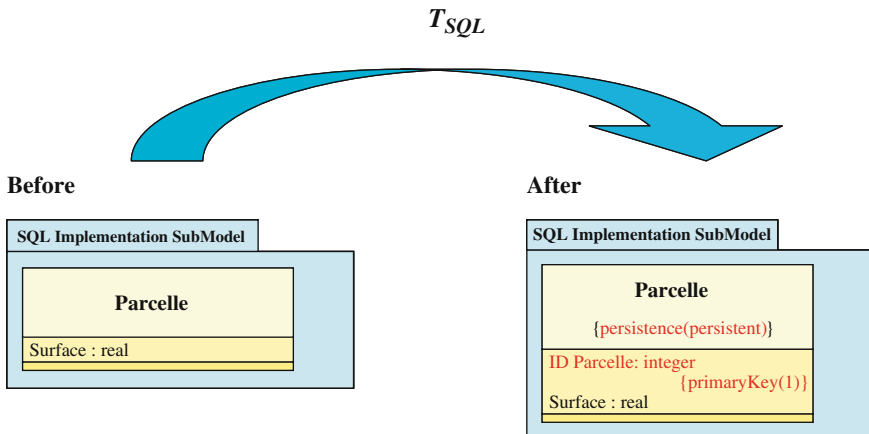


Fig. 11 The SQL transformation  $T_{SQL}$



## 5 Conclusions

The continuous integration unified process method proposed above presents a number of advantages. Below, we clarify three important advantages.

The first advantage is to have split research of excellence into the subcategories *semantic excellence* and *technical excellence*. This dichotomy introduced by the continuous integration unified process method has been obtained by superimposing a cycle of rapid prototyping in the analysis phase onto the main cycle (Fig. 6). Successive prototypes completed during this cycle of rapid prototyping are devices that form the topics of discussion and criticisms from the actors. Progressively, these prototypes tend toward “the ideal application” and the actors of the field need this. To reach this ideal state, the actors describe the business concepts, and their description becomes finer as one proceeds through the iterations of the cycle of rapid prototyping. The semantic excellence is then reached, and the model coming from the phase of analysis in the main cycle can be stabilized from the semantic point of view. In the phase of design and implementation of the main cycle, the development team has the leisure to address and to solve the technical sides linked to the production of the binary code. During this main cycle, the aim is toward technical excellence.

The second advantage is the capitalization of knowledge. The generalization of the idea to separate the business concepts from those of implementation, an idea suggested by the MDA approach, has led to the design of the software development process approach, which associates a model with each of the phases of the development cycle of an application. Thus, the software development process model, an artifact that reifies the software development process approach, groups together all the models that are associated with the development phases. Thus, the project manager has both a global view of development through the software development process model and a detailed view through each model that makes up the software development process model. It can, at any time, identify at what phase of development a concept has been introduced (business, from an associated domain, implementation, etc.) by scanning the content of the models. These models are actually “capitalization planes” of knowledge implemented at each phase needed to produce the application.

The third advantage is a gain in quality linked to automation of the evolution by the model transformations. During the development of an application, some actions or activities are conducted in a repetitive way tens, and even hundreds, of times. For instance, one should add the persistence and the primary key properties for all the concepts except those involved in a hierarchy (see Section 4.4.3). If this activity is done manually, more time will be needed than if it is done by a transformation that has been designed and implemented in the case-tools. Moreover, it is not rare that, when done manually, some of the concepts are forgotten and that these mistakes are noticed during the creation of the database. In this case, all the implementation process should be resumed. A designer, who may be poorly experienced in SQL language, may also add this

721 information to all the concepts of a hierarchy even though this is not necessary.  
 722 In this case, the coherence of the model deteriorates. In the software develop-  
 723 ment process approach, nothing forbids the designer to add these SQL proper-  
 724 ties in the design or analysis phase. The capitalization is then affected. The  
 725 implementation of the transformation  $T_{SQL}$  on the SQL implementation model  
 726 avoids this problem. The quality of the SQL implementation model is better and  
 727 the productivity is increased. It is the same for all the other transformations  
 728 described in Section 4.4. These thoughts are corroborated by the study con-  
 729 ducted by The Middleware Company [29]. This consulting business has been  
 730 in charge of conducting a productivity analysis between two teams with  
 731 an equivalent competency level: the first one was to develop an application  
 732 in a traditional way, and the second one had to create the same application  
 733 according to the MDA approach. The team working according to the MDA  
 734 approach completed the application with a time savings of 35% and a gain in  
 735 quality as the team did not have to correct development bugs. The analysts of  
 736 the consulting business attribute this gain in quality to the automated transfor-  
 737 mations of the models.  
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AQ6

AQ7

811 **A New Methodology to Automate the Transformation of GISGIS Models**  
812 **in an Iterativeiterative Development Process**

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814 <b>Query No.</b>	<b>Line No.</b>	<b>Query</b>
815 AQ1	109	816 Clarify sense/ rewrite phrase: “and only 28% of the 817 developments have to finish in delay and in the projected 818 budget”; are 28% delayed? do they finish within budget?
819 AQ2	134	820 Define acronym SCRUM.
821 AQ3	150	822 Check legend of Fig. 3; identical to that of Fig. 2.
823 AQ4	235	824 In footnote 2, clarify phrase: “or failing by a member of the 825 team”; how does this relate to term customer on-site?
826 AQ5	505	827 Define acronym SQL.
828 AQ6	782	829 In Ref. 28, provide name of publisher.
830 AQ7	783	831 In Ref. 29, provide name of publisher.

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